Biosecurity and exotic disease surveillance in the New Zealand pig industry

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

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Abstract

The New Zealand commercial pig industry is modern and highly productive. The industry is free from many of the important infectious diseases present in much of the rest of the world. However, alongside the commercial industry are a large number of non-commercial pig holdings operated with minimal attention to biosecurity. The extent to which the activities in the non-commercial sector might negatively impact the commercial sector was unknown therefore a series of projects was undertaken to explore the likelihood of an exotic disease occurring.

A risk assessment was undertaken to determine the likelihood porcine reproductive and respiratory syndrome (PRRS) virus would be introduced into New Zealand through imported fresh pork. The study estimated that at least 4.3 pig herds per year were likely to become infected with PRRS and that 36% of these incursions would spread to additional herds. It was recognized that the data describing the interactions between commercial and non-commercial pigs could be improved so a prospective study was undertaken to collect information about the movements of pigs and genetic material between farms.

To assist in development of a national surveillance programme, two additional studies were then initiated. First, a study was conducted to determine the effect of blood sample mishandling on the performance of ELISA assays and second, a retrospective analysis of data from a national abattoir-based lesion recording system (PigCheck) was conducted. These studies were done with the realization that future surveillance activities would need to incorporate creative means of generating high-quality surveillance data, from various surveillance components, using both laboratory- and field-based staff.

Investment Logic Mapping was then used to assist the industry in establishing a biosecurity and surveillance strategy. A single strategy ‘improve surveillance’ was identified as the key area for biosecurity investment. In response to this finding, modelling of potential surveillance activities was completed and a surveillance programme was proposed costing approximately $0.50 per pig annually.

The work presented in this thesis demonstrates the New Zealand pig industry is susceptible to introduction of an exotic disease and that the population of non-commercial pigs must be considered when developing biosecurity, and disease readiness or response plans for the commercial industry. The described studies show that a cost effective national disease surveillance programme can be implemented through use of a combination of existing and newly developed sources of surveillance information.

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Introduction

The New Zealand commercial pig industry enjoys a very high health status. The country is known to be free from most of the major pig diseases common in much of the rest of the world including porcine reproductive and respiratory syndrome (PRRS), Aujeszky's disease, classical swine fever, transmissible gastroenteritis, and foot and mouth disease. However, despite the current good health status and the fact New Zealand is a remote island, disease incursions including post-weaning multisystemic wasting syndrome (2003 and 2006) have occurred suggesting the industry is not impenetrable. Of particular concern for the commercial industry is the substantial and geographically widespread non-commercial pig industry in New Zealand. This sector of the industry currently operates with little guidance from, or interaction with veterinarians, the Ministry of Primary Industries (MPI), or the levy-funded commercial pig organisation (NZ Pork) and therefore any poor biosecurity practices within the sector also stand to place the commercial industry at risk of disease introduction.

In this thesis, five projects are described that explore the likelihood and mechanisms by which an exotic disease might occur in the New Zealand pig industry, and is concluded by describing the development of a biosecurity and exotic disease surveillance programme for the commercial industry. The described work coincided with two key events related to the biosecurity of the industry: First, MPI recently proposed changes to the import health standards for pig meat entering New Zealand from countries known to be endemically infected with PRRS thereby increasing the risk of introducing PRRS virus into the country; and second, MPI announced development of Government-Industry Agreements (GIA) which would shift the cost burden of exotic disease readiness and response from government, to a government-industry cost-sharing arrangement. Both of these events had a profound impact on the commercial pig industry that resulted in an urgent need to better understand the current biosecurity status of the industry and to develop a formal plan for improving areas of identified weakness, including disease surveillance.

In an effort to quantify the risk of PRRS virus introduction through importation of fresh pork from PRRS infected countries, a risk assessment was conducted. The assessment included release, exposure, and consequence models using the combination of a stochastic spreadsheet model (@RISK; Palisade Asia-Pacific Pty Limited, Milsons Point, NSW, Australia) and a spatial and stochastic simulation software for infectious disease in animal populations (InterSpread Plus; EpiCentre, Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Palmerston North, NZ). This

assessment concluded the risk of introduction was substantial, in contrast to the negligible risk of introduction that was concluded by an assessment conducted by MPI. Importantly, the work identified several areas in which the data supporting both risk assessments was either unavailable (such as the extent of interactions between commercial and non-commercial pigs, the frequency and nature of waste food feeding on non-commercial pig holdings, and the typical movement distances of pigs and semen in New Zealand) or was in disagreement (lack of consensus on rate of virus inactivation in pork, ease of control or eradication if PRRS was introduced, and the effectiveness of carcass trimming as a risk mitigation step).

To provide further data around some of these areas, a prospective study of the behaviours of both commercial and non-commercial pig owners was undertaken using postal surveys and interviews. Specifically, the study aimed to generate data that would describe the frequency and distance of movements of pigs, semen, and other potential disease vectors within and between the commercial and non-commercial sectors of the New Zealand pig industry. While the study found that the overall frequency of interaction was modest, the fact that non-commercial sites out-numbered commercial sites by perhaps as much as 50 to one, effectively made the point that biosecurity lapses in the non-commercial sector had the potential to dramatically affect the disease status of the entire country. Additionally, the study identified key activities in the commercial industry such as supply of genetics and abattoir movements that should be incorporated into an effective disease surveillance system.

Realizing disease surveillance in the pig industry needed enhancement and that there were key industry activities that would be important to target as part of a surveillance system, a study was undertaken to evaluate the effect of mishandling diagnostic serum samples on antibody-based serologic test accuracy. More than 95% of the commercial industry is served by only three veterinarians and this, combined with the fact that none of the diagnostic laboratories in New Zealand are routinely offering pig disease serologic testing suggested a reasonable potential for sample mishandling to occur. It is likely that farmers, abattoir inspectors, veterinary technicians, as well as veterinarians would be collecting blood samples as part of any future surveillance programme and therefore the effect of problems such as haemolysis, repetitive freeze-thawing, and high ambient temperatures on diagnostic serologic tests should be investigated. No prior work on this topic could be identified anywhere in the world and so the study provided information very useful to New Zealand and other developed pig industries.

Beyond active disease surveillance that could be accomplished through serologic testing, other potential components of a surveillance system were considered. In particular, a system for recording the occurrence of post-mortem disease lesions in pigs delivered to commercial abattoirs (PigCheck system) currently exists in New Zealand but had thus far been under-utilized as tool for national disease surveillance. A retrospective study of the available historical PigCheck dataset was conducted to establish the national prevalence of 22 lesions, the trend and seasonality of lesion occurrence, and to determine the relative contribution of farms versus abattoirs to the variation in lesion prevalence. The PigCheck systems is operated at a low cost, is managed by a quality assured third party that includes collection of data by trained inspectors, and makes the data available to farmers (and their nominated persons) on a near real-time basis all of which appear to support its use in a future surveillance system.

The commercial pig industry is supported through an active and capable levy-funded organisation called NZ Pork. The organisation's mandate is '*to help in the attainment, in the interests of pig farmers, of the best possible net on-going returns for New Zealand pigs, pork products and co-products*' and part of their strategy for achieving this is to establish a comprehensive biosecurity programme for the industry. In the past, NZ Pork has created a number of initiatives, communications, and training programmes to advance their efforts in improving biosecurity on farms but these have tended to be through independent and uncoordinated efforts. In 2012, a project was undertaken to establish a comprehensive biosecurity programme for the industry using a strategic planning tool called Investment Logic Mapping (ILM). The ILM framework was developed by the Victorian (Australia) government over the last ten years and provides an efficient means for a group of decision-makers to achieve consensus on problems to be solved, benefits to be realized by solving the problems, strategies to achieve the solutions, and key performance indicators to monitor progress toward achieving the desired benefits. Through facilitated discussions, the ILM was developed and it became clear that design and implementation of a national disease surveillance programme was an important strategy would help in achieving a solution to several of the problems that had been identified. In addition, the ILM framework that was conducted in such a way as to be useful for NZ Pork as they commenced negotiations with MPI on their relative contributions toward readiness and response plans for exotic diseases, as dictated by

GIA. A proposed national exotic disease surveillance plan was designed and costed as one of the outputs of the ILM process.

Chapter 2. Descriptive summary of an outbreak of porcine post-weaning multisystemic wasting syndrome (PMWS) in New Zealand

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Abstract

CASE HISTORY: Investigations were conducted to determine the cause of an acute, multi-farm outbreak of porcine respiratory disease that included diarrhoea and subsequent loss of body condition in affected pigs. A definition for post-weaning multisystemic wasting syndrome (PMWS) including both clinical and pathological features, previously developed for the pig industry in New Zealand, was applied to the current outbreak. In addition to self-reporting by owners of affected farms, local veterinarians, disease and epidemiology consultants, and animal health officials from the Ministry of Agriculture and Forestry (MAF) were involved in conducting farm visits and submission of diagnostic specimens.

CLINICAL FINDINGS AND DIAGNOSIS: Pathogens known to be endemic in the pig industry in New Zealand as well as likely exotic diseases were excluded as causative agents of the outbreak. Clinical signs including dyspnoea, diarrhoea, and rapid loss of body condition were consistent with the New Zealand case definition for PMWS. Interstitial pneumonia, pulmonary oedema, generalised lymph-node enlargement, and presence of porcine circovirus type 2 (PCV2) inclusion bodies were consistently identified in affected pigs. Classical swine fever virus (CSFV), Porcine reproductive and respiratory syndrome virus (PRRSV), and Influenza virus were ruled out, using molecular and traditional virological techniques. Spread of the disease between farms was hypothesised to be facilitated by locally migrating flocks of black-backed seagulls. The original source of the disease incursion was not identified.

DIAGNOSIS: Based on the consistent presence of circovirus-associated lesions in lymphoid tissues in combination with generalised enlargement of lymph nodes, histiocytic interstitial pneumonia, clinical wasting, and poor response to antibiotic therapy, a diagnosis of PMWS was made.

CLINICAL RELEVANCE: PMWS should be considered in the differential diagnoses of sudden onset of respiratory dyspnoea, diarrhoea, and rapid loss of body condition in young pigs in New Zealand pig herds.

KEY WORDS: Pigs, Post-weaning multisystemic wasting syndrome, Porcine circovirus, Respiratory disease, Disease investigation, Disease transmission

Abbreviations

CSFV	Classical swine fever virus
MAF	Ministry of Agriculture and Forestry
NZPIB	New Zealand Pork Industry Board

PCV2	Porcine circovirus type 2
PMWS	Post-weaning multisystemic wasting syndrome
PRRSV	Porcine reproductive and respiratory syndrome virus

Introduction

Porcine post-weaning multisystemic wasting syndrome (PMWS) was first described in Canada in 1996 (Clark 1996; Harding 1996), and associated with the presence of PCV2 soon after (Harding and Clark 1997; Ellis et al 1998). Since that time, the disease has been reported from most countries which have significant levels of commercial pig production. Australia is a notable exception, and surveillance and investigation of possible cases have so far proved negative.

Until such time that a definitive diagnostic test becomes available, PMWS remains a syndrome described by a case definition that includes both clinical and pathological features. Controversy also remains over whether the disease has a specific, as yet unidentified, causal agent, or is due to PCV2 interacting with various co-factors.

Case definitions for PMWS need to be suitably broad to ensure that outbreaks are identified, yet specific enough to avoid excessive numbers of false-positive diagnoses. The first broadly adopted PMWS case definition, including both clinical and pathological features of the disease, was published in 2000 (Sorden 2000). The elements of this early case definition included the presence of typical clinical signs (wasting/weight loss/ill-thrift/failure to thrive, with or without dyspnoea or icterus), characteristic histological lesions (depletion of lymphoid organs/tissues and/or lympho-histiocytic to granulomatous inflammation in any organ), and identification of PCV2 within the characteristic lesions. In 2005, a panel of international experts published a case definition for PMWS that explicitly stated a requirement for clinical signs at the herd level, and provided formulae for calculating PMWS-related mortality rates that emphasised recent changes in a farm's performance (Anonymous 2005).

While the evidence is convincing that PCV2 is involved in PMWS, the role of this virus and other contributing factors remains unresolved. Other authors have thoroughly reviewed this topic, and it remains uncertain whether PMWS is caused by interactions between PCV2 and a variable number of co-factors, both infectious and non-infectious, or whether a yet-to-be identified novel agent is necessary for disease expression (Chae 2004; Darwich et al 2004; Chae 2005; Ostanello et al 2005).

PMWS was not reported in New Zealand until 2003, when the disease was identified in a group of pig farms in the North Island; the index case was a farm in the Waikato region, south of Auckland. The outbreak was characterised by the acute appearance of wasting and mortality in large numbers of young pigs post-weaning, preceded by a short prodromal period of reproductive failure in sows. After investigation of alternative

diagnoses, the herd was confirmed with PMWS in September 2003, using a slight modification (Stone 2004) of the original case definition put forward by Sorden (2000). Tracing procedures identified several at-risk herds which had either supplied the index farm, or received pigs or risk goods from it. Investigations of these herds excluded semen as a source of infection for the index farm, but identified movement of weaner pigs, feed and fomites as likely transfer mechanisms. A joint eradication programme was instituted, by industry and government, effectively stopping further spread of the disease through depopulation of affected farms. Details of that outbreak have been reported elsewhere (Bastianello 2004; Rawdon et al 2004; Stone 2004; Stone and Kittelberger 2004; Loth and Stone 2005; Stone 2005) and are not reviewed in detail here.

New Zealand is currently free of PRRSV, transmissible gastroenteritis, CSFV, foot-and-mouth disease, and has a very limited presence of swine influenza. Porcine circovirus is endemic and ubiquitous in New Zealand; evidence of porcine circovirus (type not distinguished) in pigs was reported in 1991 (Horner 1991), and since the two sub-types were distinguished, both porcine circovirus type 1 and PCV2 have been detected in abattoir samples of pigs in New Zealand as recently as 2003 (Tham and Hansen 2003). Given New Zealand's freedom from most significant viral pig diseases common in many other countries, disease outbreaks in New Zealand with respiratory or enteric signs that present in any kind of atypical pattern are quickly recognised by farmers and veterinarians.

The aim of this study was to determine the cause of the outbreak of a disease in pigs in Canterbury, in the South Island of New Zealand. Equal emphasis was placed on ruling out exotic and other endemic pathogens. Efforts were also made to identify the source of the disease incursion, and factors important in its spread between farms.

Case history

Over a two-week period in January 2006, two outdoor pig-breeding farms in the Canterbury region, South Island, New Zealand, reported an outbreak of dyspnoea, diarrhoea, and subsequent wasting in 8 to 14-week-old pigs. The two farms were located approximately five km apart, and no pig or fomite contact was identified between them. A series of diagnostic investigations was undertaken to determine if PMWS was occurring on these farms. Fourteen additional farms were subsequently affected, including four other breeding herds and 10 finishing facilities. Figure 7 on Page 82 shows the locations of farms involved in the outbreaks in 2003 and 2006.

Clinical and pathological findings

Farm description

Breeding herds in this outbreak were all housed outdoors, farrowed in individual deep-bedded farrowing huts, and piglets were weaned at 25 to 31 days of age. Weaned piglets from some of these farms remained on-site but others were relocated to various pig finishing facilities ranging from deep-bedded, transportable sheds (‘eco-barns’) to conventional environmentally controlled weaner rooms.

The affected pigs on all farms were eight to 14-weeks old. The specific practices for relocating weaned pigs varied from farm to farm. Some farms sold pigs to off-site finishing farms at the time of weaning, some retained the pigs for five to six weeks and then sold them to off-site finishing farms, and others finished the weaned pigs on their own farm. PMWS occurred with similar severity and prevalence, regardless of relocation event or housing type.

Clinical presentation

The clinical expression of the disease typically began with a decrease in feed intake, followed 24 to 48 h later by moderate pyrexia (41.5 to 43°C), dyspnoea and/or diarrhoea; in several herds, palpebral oedema, conjunctivitis and nasal discharge were early indicators of the disease. Coughing was not a feature. Over the subsequent 48 to 72 h, dyspnoea became more pronounced, and rapid loss of body condition became evident. In some affected groups, conjunctivitis, mucopurulent nasal discharge, and nasolachrymal staining became quite pronounced during this stage. Beyond this stage, yellow-coloured diarrhoeic faeces were commonly observed as was continued loss of body condition and enlargement of superficial lymph nodes. New pigs continued to be affected throughout the susceptible age of 8 to 14 weeks.

Outbreak investigation

January 2006

In early January 2006, two unrelated outdoor breeding farms reported decreased feed intake, dyspnoea, diarrhoea, conjunctivitis, nasolachrymal discharge and subsequent loss of body condition in weaned pigs 8 to 14 weeks of age. Additionally, weaned pigs recently sold from one of the breeding farms were also showing similar signs on recipient farms. The affected farmers sought advice from their respective specialist pig veterinarians, who independently made farm visits to their clients and submitted tissues to a diagnostic laboratory.

Attending veterinarians euthanised affected pigs during their visits, and described: interstitial pneumonia; antero-ventral lung consolidation; ulcerative and non-ulcerative colitis; generalised enlargement of lymph nodes; and excess fluid containing fibrin in the peritoneal, pleural, and epicardial cavities of individual pigs.

The small size of the pig industry in New Zealand and the limited number of pig veterinarians that service the industry facilitated communication. Through this informal mechanism, the two veterinarians involved with the index farms recognised similarities in the clinical signs and lesions and approached the New Zealand Pork Industry Board (NZPIB). The NZPIB, with permission from the farm owners, engaged the services of a third veterinary consultant who had been involved with the PMWS outbreak investigation in the North Island during 2003.

The consulting veterinarian visited the two index farms as well as a third farm that was purchasing eight-week-old pigs from one of the index farms. All farm visits were attended jointly by the local practitioners and the consulting veterinarian. Clinical signs and gross pathology were similar to those noted during the initial visits in early January. PMWS was considered a likely diagnosis, but given the fact that both farms had no contact with uncooked food waste, had not changed their source of genetic introductions for at least two years, and had no other obvious breaches in biosecurity, it was necessary to continue efforts to rule out endemic pathogens. In consultation with the NZPIB, pig specialists and epidemiologists from Massey University were asked to participate in further investigations.

February 2006

In early February 2006, visits were again made to the two index farms and three additional farms that were purchasing eight-week-old pigs from one of the case farms. Massey University staff, accompanied by the local attending veterinarians, collected crude morbidity and mortality data from each piggery, and completed additional clinical and post-mortem examinations. Samples were collected from multiple pigs, for submission to a diagnostic laboratory.

At this point, two breeding herds and three farms purchasing pigs from the affected breeding farms were believed to be affected. A list of possible differential diagnoses was developed. The list included PMWS, bacterial/mycoplasmal pneumonia, salmonellosis, and mycotoxicosis (given the extensive use of straw bedding materials in the outdoor production units). Additional concerns about PRRSV and CSFV were raised, resulting in the initiation of an exotic disease investigation by MAF.

Animal health officials from MAF conducted extensive testing through clinical and post-mortem examination, serology, and molecular and traditional virology techniques on the index farms and the most acutely affected related pig-finishing facilities. All tests were negative for PRRSV and CSFV.

March 2006

Since initial recognition of the disease, farmers reported that the severity of disease appeared to be cycling through phases of improvement and deterioration every 7 to 10 days. A periodic reduction in disease severity, characterised by the appearance of fewer acutely ill pigs, apparently good response to antibiotic therapy in affected pigs, and an overall decline in mortalities, would then be followed by a period of increasing morbidity, a return to the more usual poor response to therapy, and a more severe expression of clinical signs.

At this point in the outbreak, producers on the affected farms had become quite proficient at identifying pigs very early in the course of the disease. Through rapid relocation of these pigs to a hospital pen, and coupled with aggressive parenteral antibiotic therapy, mortality could be minimised and reasonable numbers of pigs returned to health, albeit at least three to four weeks behind their age cohorts in bodyweight. This contrasted with experiences from the outbreak in the North Island in 2003, where recovery to health was rare.

Local veterinarians involved in the outbreak began reporting additional suspect herds, prompting further investigation by Massey University staff, the local veterinarians, and NZPIB representatives. Seven farms were visited, comprising three breeding herds and four piggeries receiving pigs from the breeding farms. Pigs from eight to 14 weeks old on each farm were exhibiting the same clinical signs noted on the index farms, *viz* dyspnoea, diarrhoea, loss of body condition and elevated mortality. Post-mortem examinations of euthanised pigs were made on several of the farms, confirming gross pathology similar to previous workups, i.e. generalised lymphadenopathy, segmental areas of mild enteritis or colitis, and diffuse interstitial pneumonia with oedema and variably severe consolidation of antero-ventral lobes. Samples from two of the farms were submitted for diagnostic testing.

Diagnostic testing

Histopathological examination of samples collected in early January revealed lymphocyte depletion, loss of cortico-medullary definition, histiocytic infiltration, multinucleated histiocytes, and botryoid inclusion bodies (PCV2) in lymph nodes,

spleen, and peribronchial lymphoid tissue; these changes were similar to those reported from affected pigs in the outbreak in 2003 (Bastianello 2004). Lung tissue showed a generalised interstitial pneumonia, and both suppurative and histiocytic changes. While histopathological lesions were highly suggestive of PMWS, even in this early stage of the outbreak, two additional elements needed to be established in order to meet the New Zealand case definition for PMWS, i.e. ruling out other endemic pathogens and verifying poor response to antibiotic therapy.

Occasional pigs presented with mild ulcerative colitis, and had adherent spirochaetal organisms present. Aerobic culture yielded *Streptococcus suis* type 2 from the lung of several pigs; an untypable *Salmonella* sp was also isolated from the colon of pigs on both of the index farms.

Diagnostic test results and histopathology from subsequent submissions in late January and February 2006 confirmed the presence of porcine intestinal spirochaetosis, *Haemophilus parasuis*, *Mycoplasma hyopneumoniae*, *Pasteurella multocida*, *Streptococcus suis*, and *Escherichia coli* enteritis. However, the consistent presence of circovirus-associated lesions in lymphoid tissues in combination with generalised enlargement of lymph nodes, histiocytic interstitial pneumonia, clinical wasting, and poor response to antibiotic therapy ultimately led to the diagnosis of PMWS, in early March 2006.

Pigs younger than eight weeks and older than 14 weeks of age showed none of the characteristic clinical signs of PMWS. No unusual clinical signs were noted in any of the breeding herds, nor were production indicators, including returns to oestrus, conception rate, farrowing rate, or number detected not pregnant, found to be outside the expected normal range for the respective farms.

PCV2 from the outbreak in 2006 was identified using the polymerase chain reaction (Fenaux et al 2000) in lung tissue collected from an acutely affected nine-week-old pig; the complete genome was then sequenced. Efforts to recover and sequence virus in archived tissue from the outbreak in 2003 have not yet been successful. An unrooted phylogenetic tree (Figure 8, Page 83) was constructed to compare the New Zealand isolate with nucleotide sequences from a range of other PCV2 sequences available from GenBank and the National Centre for Biotechnology Information. The New Zealand isolate shared between 94 and 100% similarity with the other viruses shown. Genomic alignments were performed using the AlignX engine within Vector NTI Advance 10.3.0

(Invitrogen Corporation, Carlsbad CA, USA); the phylogenetic tree was constructed using TreeView 1.6.6 (Glasgow University, Scotland, UK).

PMWS effect on pig performance

Group level performance data was collected from 11 farms involved in the outbreak. Total mortality post-weaning was self-reported by cooperating farmers and is presented in Table 4 on Page 80. Mortality (mean = 8.57%) was significantly increased after onset of PMWS. Mortality counts included all deaths, regardless of cause. There were inadequate numbers of groups represented from each farm to permit calculation of the statistical contribution of each farm to the overall differences in performance pre- and post-outbreak. A two-sample t-test was conducted to detect overall differences in performance pre- and post-outbreak and it should be noted that specific husbandry levels and environments differed between farms limiting the confidence in the reported means.

The mean cumulative eight-week rolling mortality rate reported from farms involved in the outbreak in 2003 was 25.3% (Bastianello 2004). This was substantially higher than the rate in the outbreak reported here, but no pre-outbreak mortality rates from those farms specifically affected in 2003 were reported to permit a direct comparison.

Discussion

By mid-April 2006, PMWS had been identified on 16 farms; six breeding herds and 10 farms related to those breeding herds through the movement of weaned pigs. The process for arriving at the final diagnosis in <60 days was highly dependent on close communication between the local community of pork producers and their veterinarians. This clearly demonstrates the value of being able to share disease information between veterinarians and producers in a professional and confidential manner. The early involvement of the NZPIB was a critical link for facilitating involvement of outside expertise, consensus building among the different constituencies, and significant funding of diagnostic testing.

A number of factors revealed during the investigation process were notable. Firstly, most reports of PMWS outbreaks in commercial pig industries outside New Zealand have been complicated by the presence of PRRSV in those same industries. PRRSV has been reported as a significant co-factor for expression of the disease (Harms et al 2001) but in New Zealand it is clear that PMWS presented in a form which included lesions of interstitial pneumonia even in the absence of PRRSV. The clinical features of the disease in the outbreak in Canterbury showed distinct differences, such as the early

development of dyspnoea, marked conjunctivitis, and much more severe enlargement of lymph nodes compared with those seen in the outbreak in the North Island, but that were not unique from those described amongst PMWS outbreaks in other countries.
Secondly, every case farm involved in the early stages of the outbreak in Canterbury either had an outdoor breeding herd or purchased recently weaned pigs from a breeding herd that was managed outdoors. Breeding herds involved in this outbreak were located in a cluster near the edge of Christchurch, and finishing farms infected from them were more widely dispersed. Of interest was exceptionally large numbers of southern black-backed seagulls (*Larus bulleri*) that circulated in the region during the outbreak. Canterbury is bounded by the eastern coast of New Zealand's South Island, and its tidal rivers are recognised as major breeding grounds for these seagulls, which are scavengers and occupy diverse habitats, often remote from the sea. Water birds have previously been implicated in the transmission of pig pathogens (Oxberry and Hampson 2003), and it seems feasible that they could have played a role in the transmission of PMWS in Canterbury, as physical or biological vectors, given the predilection for the occurrence of the disease in outdoor breeding farms. Seagulls in the region have become habituated to scavenging feed from pigs housed outdoors. Populations of lactating sows are particularly favoured by the seagulls, as these sows are fed *ad libitum* in unenclosed feeders, making the feed easily accessible throughout much of the day. The seagulls have developed a feeding pattern whereby they descend upon a farm during the period around feed delivery, scavenge as they are able, then relocate to neighbouring farms to repeat the process. Single flocks can number in excess of 1,000 birds at any time, as determined by physical counts after bird reduction programmes on affected farms; multiple flocks are active in the area at any time (Figure 9, Page 84). With their large webbed feet, these seagulls present a risk of mechanically transporting pig faeces and pathogens among farms. However, their potential role as a biological or replicating vector for PMWS cannot be ascertained until the necessary and sufficient causes of the disease are identified.
Thirdly, feeding of waste food was hypothesised as a possible source of the PMWS incursion into Canterbury, as was similarly suggested in the outbreak in the North Island in 2003 (Stone 2004). The city of Christchurch, including an international airport, is located approximately 20 km from the index herds. At least some waste food from the city is known to be fed to pigs by non-commercial farmers in the area but the extent and distribution of the practice is unknown. Since 2005, all waste food fed to pigs in New

Zealand is required to be cooked to 100°C for one hour. During the PMWS investigation, several farms in the Canterbury region were identified as feeding food waste but were unaware that regulations had been enacted that required thorough cooking of the material. The farms involved in this practice were small operations and had insufficient records to determine whether they had experienced any clinical signs suggestive of PMWS. Until the causal pathway for PMWS is clearly delineated, it will not be possible to quantify the risk of PMWS that is associated with the feeding of waste food to pigs.

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References

*__Anonymous.__ PMWS Case Definition (Herd Level) October 2005. http://www.pcvd.org/documents/Belfast_Presentations_PCVD/Final_pmws_case_definition_EU_October_2005.doc (accessed July 21, 2008). The Control of Porcine Circovirus Diseases (PCVDs): Towards Improved Food Quality and Safety, European Union Sixth Framework Programme Project No. 513928, Brussels, Belgium, 2005

Bastianello S. Pathology of post-weaning multisystemic wasting syndrome in New Zealand pigs. *Surveillance* 31, 3-7, 2004

Chae C. Postweaning multisystemic wasting syndrome: a review of aetiology, diagnosis and pathology. *Veterinary Journal* 168, 41-9, 2004

Chae C. A review of porcine circovirus 2-associated syndromes and diseases. *Veterinary Journal* 169, 326-36, 2005

***Clark EG.** Pathology of postweaning multisystemic wasting syndrome of pigs. *In Proceedings of: 'Western Canadian Association of Swine Practitioners'*. Alberta, Canada Pp 22-5. (Western Canadian Association of Swine Practitioners) 1996

Darwich L, Segales J, Mateu E. Pathogenesis of postweaning multisystemic wasting syndrome caused by Porcine circovirus 2: An immune riddle. *Archives of Virology* 149, 857-74, 2004

Ellis J, Hassard L, Clark E, Harding J, Allan G, Willson P, Strokappe J, Martin K, McNeilly F, Meehan B, Todd D, Haines D. Isolation of circovirus from lesions of pigs with postweaning multisystemic wasting syndrome. *Canadian Veterinary Journal* 39, 44-51, 1998

Fenaux M, Halbur PG, Gill M, Toth TE, Meng XJ. Genetic characterization of type 2 porcine circovirus (PCV-2) from pigs with postweaning multisystemic wasting syndrome in different geographic regions of North America and development of a differential PCR-restriction fragment length polymorphism assay to detect and differentiate between infections with PCV-1 and PCV-2. *Journal of Clinical Microbiology* 38, 2494-503, 2000

***Harding JC.** Postweaning multisystemic wasting syndrome: Preliminary epidemiology and clinical findings. *In Proceedings of: 'Western Canadian Association of Swine Practitioners'*. Alberta, Canada p 21. (Western Canadian Association of Swine Practitioners) 1996

Harding JS, Clark EG. Recognizing and diagnosing postweaning multisystemic wasting syndrome (PMWS). *Swine Health and Production* 5, 201-3, 1997

Harms PA, Sorden SD, Halbur PG, Bolin SR, Lager KM, Morozov I, Paul PS. Experimental reproduction of severe disease in CD/CD pigs concurrently infected with type 2 porcine circovirus and porcine reproductive and respiratory syndrome virus. *Veterinary Pathology* 38, 528-39, 2001

Horner GW. Pig circovirus antibodies present in New Zealand pigs. *Surveillance* 18, 23, 1991

Loth L, Stone M. Weaner pig mortality rates on New Zealand farms affected by PMWS. *Surveillance* 32, 3-6, 2005

Ostanello F, Caprioli A, Di Francesco A, Battilani M, Sala G, Sarli G, Mandrioli L, McNeilly F, Allan GM, Prosperi S. Experimental infection of 3-week-old conventional colostrum-fed pigs with porcine circovirus type 2 and porcine parvovirus. *Veterinary Microbiology* 108, 179-86, 2005

Oxberry SL, Hampson DJ. Epidemiological studies of *Brachyspira pilosicoli* in two Australian piggeries. *Veterinary Microbiology* 93, 109-20, 2003

Rawdon T, Lawton D, Johnstone A, Stone M, Spencer Y, Johnson L. Investigation of post-weaning multisystemic wasting syndrome. *Surveillance* 31, 11-5, 2004

Sorden SD. Update on porcine circovirus and postweaning mulitsystemic wasting syndrome (PMWS). *Swine Health and Production* 8, 133-6, 2000

Stone M. Response to first diagnosis of post-weaning multisystemic wasting syndrome. *Surveillance* 31, 8-14, 2004

Stone M, Kittelberger R. Serological survey for PRRS during a response to PMWS. *Surveillance* 31, 15-7, 2004

Stone M. PMWS in New Zealand: Surveillance, diagnosis, and risk factors for affected farms. *thesis*, Massey University, Palmerston North, NZ, 2005

Tham K, Hansen M. Detection of porcine circovirus types 1 and 2 in abattoir-slaughtered pigs in New Zealand. *Surveillance* 30, 3-5, 2003

Tables

Table 4. Post-weaning mortality rates of groups of pigs before and after diagnosis of post-weaning multisystemic wasting syndrome on eleven farms in the Canterbury region of New Zealand.

	Number of groups (n)	Mortality (%)	SD	Min	Max
Pre-outbreak	34	1.14[a]	1.27	0	4.05
Post-outbreak	123	8.57[a]	5.79	0	23.44

[a] Mortalities before and after the outbreak differ significantly ($p<0.0001$)

SD = standard deviation; Min = minimum; Max = maximum

Figures

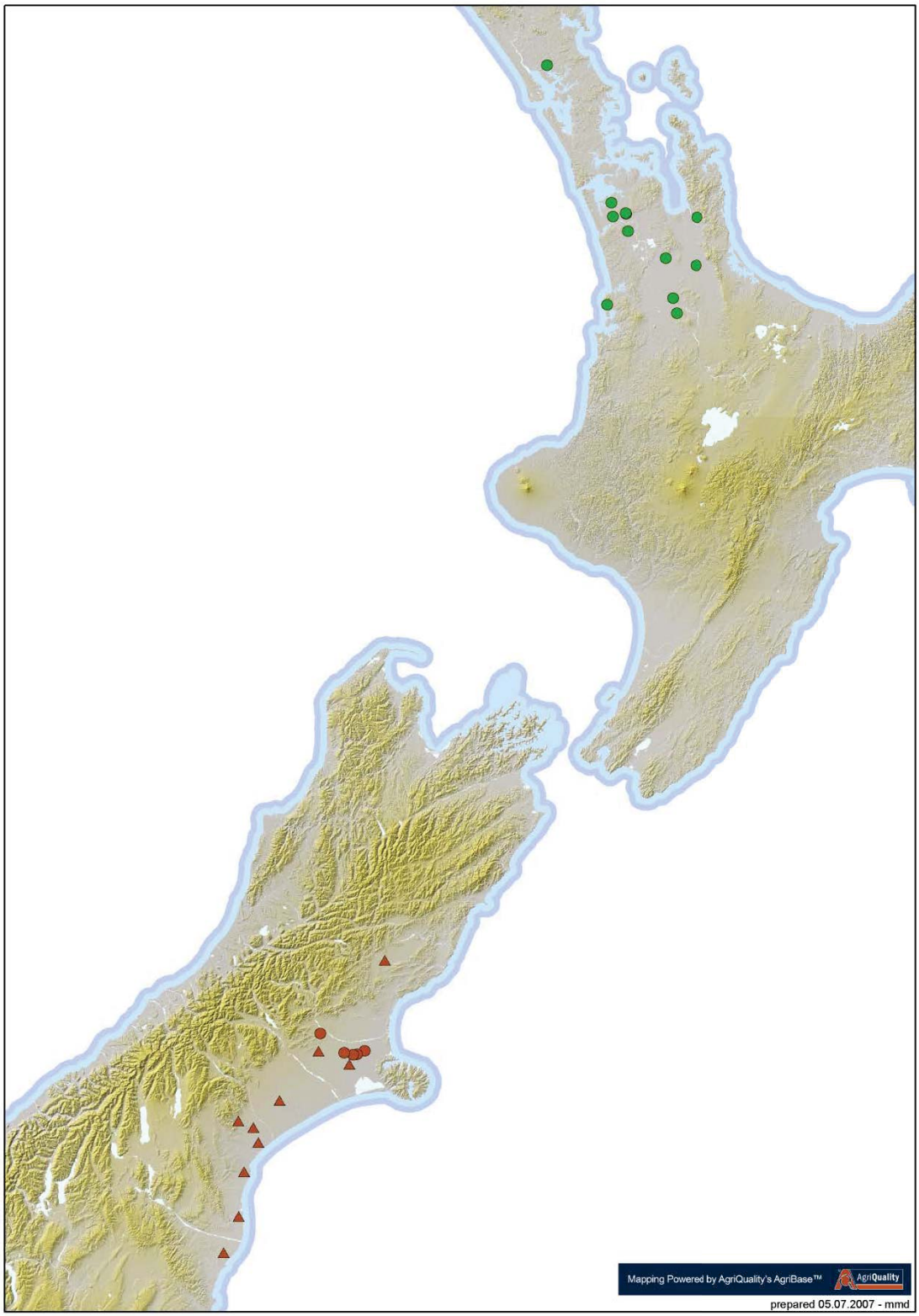

Figure 7. Location of pig farms involved in post-weaning multisystemic wasting syndrome outbreaks in 2003 (North Island) and 2006 (South Island). (● = breeding herds ± growing pigs; ▲ = growing pigs only).

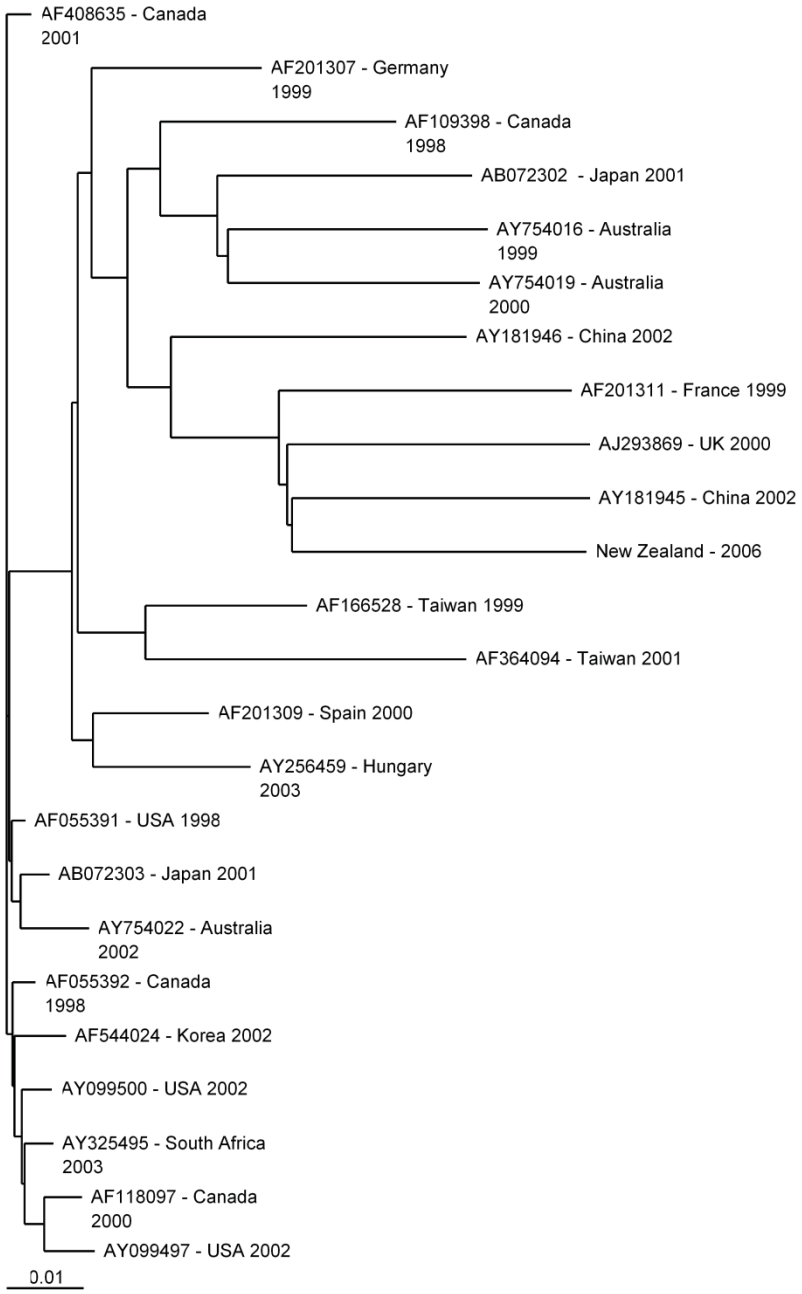

Figure 8. Unrooted phylogenetic tree based on full nucleotide sequences of porcine circovirus type 2 isolates. GenBank identifiers for each isolate are given, followed by country of origin and year. The bar equals 1% difference in nucleotide homology between two sequences.

Figure 9. Large flock of southern black-backed seagulls (*Larus bulleri*) above an outdoor pig-breeding herd in Canterbury, in the South Island of New Zealand.

Chapter 3. Analysis of the risk of introduction and spread of porcine reproductive and respiratory syndrome virus through importation of raw pigmeat into New Zealand

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Abstract

AIMS: To determine the frequency with which porcine reproductive and respiratory syndrome (PRRS) virus (PRRSV) would become established in a non-commercial pig herd in New Zealand due to illegal feeding of uncooked food waste containing virus-contaminated pigmeat. To determine the likelihood of a single incursion resulting in a multi-farm outbreak of the disease, and describe the spatio-temporal characteristics of such an outbreak.

METHODS: A Monte Carlo simulation model was constructed to determine the expected annual frequency of PRRSV infection being initiated in a non-commercial pig herd as a result of inadvertent feeding of pigmeat imported from countries endemically infected with the disease. Once the likelihood of PRRSV becoming established in a single pig herd was determined, stochastic spatially explicit infectious disease modelling software was utilised to model the temporal and spatial characteristics of the resulting epidemic.

RESULTS: Assuming the proportion of imported pigmeat remained at current levels, consumption patterns of pigmeat in households in New Zealand remained steady, and limited compliance with recently reintroduced regulations to prevent feeding of uncooked food waste, a mean of 4.3 pig herds per year were predicted to become infected with PRRSV. Simulation modelling of PRRSV epidemics related to initial infection of a non-commercial farm produced an estimate that 36% of these incursions would spread from the initial herd, and that these outbreaks would involve 93 herds on average in the first year. By increasing the estimated persistence of PRRSV infection in small herds, an average of 205 herds became infected in the first year.

CONCLUSIONS: Given a mean of 4.3 infected premises per year and a 36% probability of infection spreading beyond the initial infected herd, there was a 95% likelihood of a multi-farm PRRS outbreak occurring within three years.

CLINICAL RELEVANCE: Introduction of PRRSV through importation of virus-contaminated pigmeat presents a high risk for establishment of the disease in the pig industry in New Zealand.

KEYWORDS: PRRS, PRRSV, Porcine reproductive and respiratory syndrome virus, Infectious disease, Waste food, Risk analysis

Abbreviations

NZPIB	New Zealand Pork Industry Board
PCR	Polymerase chain reaction

POT	Probability of transmission
PRRS	Porcine reproductive and respiratory syndrome
PRRSV	Porcine reproductive and respiratory syndrome virus

Introduction

Porcine reproductive and respiratory syndrome (PRRS) is caused by an Arterivirus of swine that was first described in 1991 in Europe (Terpstra et al 1991), followed closely by identification of a related virus in the United States of America (USA) (Collins et al 1992). Comparisons of whole and partial genomes of the European 'Lelystad' or 'Type 1' and North American 'NA-PRRS' or 'Type 2' prototype viruses indicated that the two viruses shared 55–79% nucleotide homology (Murtaugh et al 1995). A considerable degree of evolution has continued to occur since discovery of the virus as a result of both genomic mutation (Stadejek et al 2006; An et al 2007) and recombination (Fang et al 2007).

As the name of the disease suggests, the virus is capable of causing overlapping clinical signs that represent both reproductive and respiratory manifestations. In its reproductive form, abortion, pyrexia, anorexia, and occasionally death have been reported in PRRSV-infected pregnant sows (Hurd et al 2001). All ages of pigs are susceptible to the effects of PRRSV-induced interstitial pneumonia which is often accompanied by secondary viral or bacterial complications. Younger pigs seem to be more susceptible to the respiratory form of the disease than do older or adult pigs (Rossow 1998).

Infection of a farm with PRRSV can result in severe production, welfare, and financial losses. The literature describing financial costs associated with PRRS was extensively reviewed in the 2003 PRRS compendium, and on-going costs of endemic infections were estimated to be between US$6.25 and 15.25 per pig marketed annually (Holck and Polson 2003). An evaluation of the aggregate cost of PRRS to the entire pig industry in the USA was published in 2005 and suggested losses of nearly US$600 million per year or approximately US$5.80 per pig marketed (Neumann et al 2005).

Since its initial recognition in the 1980s, PRRS has spread rapidly around the world and within affected countries. Few countries have avoided becoming affected by the disease but both Australia and New Zealand have remained free of the disease, due in large part to their strict biosecurity measures. Many studies have been conducted to evaluate the likelihood of specific events leading to pig-to-pig or farm-to-farm transmission, including mechanical vectors (Dee et al 2002; Otake et al 2002b; Otake et al 2002c; Dee et al 2003), insects (Otake et al 2002d; Schurrer et al 2004; Schurrer et al 2005), wildlife (Hooper et al 1994; Zimmerman et al 1997; Trincado et al 2004), semen (Yaeger et al 1993; Swenson et al 1994), and embryos (Prieto et al 1996; Randall et al

1999; Mateusen et al 2006). Additional data are available that estimated the infectious dose for semen, oral, aerosol, and parenteral exposure (Hermann et al 2005).

While there is near uniform agreement that infected pigs and semen are likely responsible for most PRRSV transmission events and others playing a less important role, the special cases of aerosol spread between farms and infection through consumption of PRRSV-infected pigmeat remain controversial. Aerosol transmission of the virus has been documented in an experimental setting from distances of 1.0–150 m (Torremorell et al 1997; Wills et al 1997a; Lager and Mengeling 2000; Otake et al 2002a). While few of these experiments contained enough replication to obtain robust estimates of the probability of infection at prescribed distances, preliminary data published recently indicated that when naïve pigs were placed nearby (<120 m) a population of actively infected pigs, infection by aerosol transmission occurred on approximately 30% of occasions (Pitkin and Dee 2007). Because of the difficulty emulating true field conditions in a laboratory setting, many of the reports that have suggested an important role for aerosol transmission have been in the form of case reports (Torrison et al 2001; Desrosiers 2002; Mohr and Rossow 2002; Daniels 2003; Desrosiers 2004), and fewer have originated from experimental work. Despite that, the peer-reviewed literature is consistent in reporting the importance of 'local spread' if not truly 'aerosol' spread.

A large case-control study conducted in Denmark concluded that biosecurity measures were inadequate to prevent infection by PRRSV, and related modelling suggested a herd located within 300 m of an infected herd was 45 times more likely to become infected compared with a similar farm 3 km away (Mortensen et al 2002). Additional work by scientists in North America investigating the epidemiological features of PRRSV-infected herds reached similar conclusions that 'area spread' was likely a significant contributor to between-farm transmission of the virus (Lager et al 2002; Larochelle et al 2003).

The possibility of infection with PRRSV through consumption of contaminated pigmeat has been convincingly established. In a study in the Netherlands, pigs were experimentally infected with either Type 1 or Type 2 PRRSV, slaughtered, and skeletal muscle harvested 11 days later. Muscle samples were then fed to naïve pigs over a two-day period, to determine if oral transmission would occur. All naïve pigs consumed the raw pigmeat and became infected by six days following feeding (24/24 pigs exposed to meat from the Type 1-infected donor pigs, 16/16 pigs exposed to the Type 2) (van der

Linden et al 2003). A similar study was subsequently conducted in Canada, that evaluated potential infectivity of skeletal muscle and serum samples derived from 1,027 market-age pigs slaughtered at a commercial abattoir (Magar and Larochelle 2004). Seventy-four percent of the serum samples contained antibodies to PRRSV; 4.3% of serum samples and 1.9% of skeletal muscle samples (19/1,027 samples) were positive for PRRSV by polymerase chain reaction (PCR). Only 1/19 PCR positive skeletal muscle samples was positive by virus isolation. Eleven of the 19 PCR-positive meat samples were divided into smaller pieces and fed to naïve pigs over a two-day period. All exposed pigs consumed the raw pigmeat, and 63% became infected. A more recent study evaluated the risk associated with contaminated pigmeat but in a slightly different context (Cano et al 2007). After experimentally infecting a group of pigs with PRRSV, skeletal muscle was harvested seven days later. The meat samples were stored at −20°C for one month then thawed and left at refrigerator temperature (4°C) for up to seven days. The investigator contaminated his gloved hands with meat juice exudate collected from meat samples on Days 0 and 1 post-thawing and then allowed naïve pigs to casually interact with his hands 0, 15, or 30 min later. Additionally, meat samples from Days 0 to 7 post-thawing were homogenised and injected into naïve pigs. Pigs exposed to the meat juice exudate, and those exposed to the thawed meat samples, became infected with PRRSV.

Persistent infection is an important feature of PRRS. While viraemia seems to be largely diminished by five to six weeks post-infection (Yoon et al 1993; Wesley et al 1998), persistence in tissues remains for an extended period. The virus has been isolated from lymph-associated tissues for at least 22 weeks (Wills et al 1997b), and detected using PCR beyond 32 weeks post-infection (Rowland et al 2003; Wills et al 2003).

Little work has been published that has attempted to model the spread of PRRSV between herds. Several studies have been published that characterised geospatial relatedness amongst multiple infected herds with PRRSV infection (Goldberg et al 2000; Mondaca-Fernandez et al 2006; Mondaca-Fernandez and Morrison 2007) but did not attempt to predict the pattern or extent of spread of the disease. As part of an import risk analysis, biosecurity officials in New Zealand identified the biological pathways from entry of PRRSV (via imported pigmeat) to the point at which an initial herd would become infected (Anonymous 2006). However, those authors did not construct any quantitative estimates of the probabilities associated with steps in the pathway, instead suggesting that the overall likelihood of exposure was ‘very low’. While direct

consequences of the disease on an initial herd were expected to be significant, the risk of spread to secondary herds was considered ‘negligible’.

Presented here are the findings of a study to quantify the risk of a pig herd in New Zealand becoming infected with PRRSV as a result of the importation of contaminated raw pigmeat. Additionally, a stochastic simulation model has been used to characterise the likelihood, extent, and temporal features of PRRSV transmission to secondary herds over a 12- or 36-month period. Information generated from these analyses will provide essential data for stakeholders involved in the assessment of recently proposed revisions to the New Zealand import health standards for pigmeat.

Materials and methods

Two sequential modelling efforts were undertaken to determine the frequency with which PRRSV infection would be initiated in a pig herd in New Zealand due to feeding uncooked food waste containing virus-contaminated pigmeat, and further evaluate the likelihood and geospatial characteristics of a subsequent multi-herd PRRSV epidemic. First, a release and exposure assessment was conducted to determine the frequency with which PRRSV could be expected to infect at least one pig on a pig-owning premises as a result of the importation of pigmeat harbouring infectious PRRSV. Second, a consequence assessment was conducted using a simulation model to characterise the likelihood and scale of a multiple herd outbreak of PRRS occurring after the first pig-owning premises became infected.

Release and exposure assessment

A stochastic model was constructed using @RISK 4.5 (Palisade Asia-Pacific Pty Limited, Milsons Point, NSW, Australia), a Monte Carlo simulation add-in for Microsoft Excel (Microsoft Corporation, Redwood, USA), to determine the annual frequency of pig owning premises in New Zealand becoming infected with PRRSV through the importation of PRRSV-contaminated pigmeat. The model constructed a chain of sequential events, and their associated probabilities and frequencies, beginning with importation of contaminated raw pigmeat and finishing with consumption of an infectious dose of PRRSV, through feeding of food waste, by a domestic pig in New Zealand. The final model provided an estimate of the number of pig-owning premises that could be expected to become infected with PRRSV annually; the model was constructed in such a way as to allow a sensitivity analysis of important steps in the chain.

Of key importance in the modelling exercise was the role of individuals who raised pigs in a non- or para-commercial setting, many of whom were known both from herd visits for veterinary examination and from evidence obtained in previous investigations of multi-herd disease outbreaks in New Zealand, to feed food waste routinely or opportunistically. This model considered the exposure risk using survey data on consumption of pork by households, which included consumption both within the home and in meals consumed elsewhere. However, the exposure risk was based on calculations that considered food waste in the context of being entirely generated in the home kitchen. Exploratory enquiries made during this study suggested that the proportion of product which became raw waste might be higher from butchers, restaurants, and other food service establishments, as compared with food waste generated in the home, and that the waste would be more likely distributed to multiple herds, increasing the overall risk. However, since the size of any difference in scale of exposure could not be determined, this waste was assumed to carry the same exposure risk as if it had been produced in the home. The model was constructed using five compartments, as shown in Figure 10 on Page 121; Table 5 on Page 113 contains a detailed description of all variables used in the model.

Step 1. Estimate of the annual quantity of PRRSV-infected pigmeat entering New Zealand

Step 1 in the assessment estimated the annual quantity of PRRSV-infected pigmeat entering New Zealand. To determine this, knowledge of three events was required: the proportion of pork consumed in New Zealand that would be imported from a PRRS-affected country (IMPORT_PCT), the proportion of imported pork expected to contain a contagious level of PRRSV (CONTAMINATION_P), and the proportion of imported pork expected to be processed in a manner that would be expected to kill any PRRSV present (IMPORT_PROCESS_P).

IMPORT_PCT was set to a point value of 0.42. This represented the proportion of pigmeat consumed in New Zealand that is currently imported, primarily from Australia, Sweden, the USA, and Canada (Anonymous 2004b). If PRRS-infected countries were approved to export raw pigmeat into New Zealand, the proportion of national pigmeat consumption that was imported, compared with that produced domestically, would be likely to increase because the number of potential pigmeat suppliers would rise dramatically. The proportion of imported pigmeat which originated in PRRS-infected countries, i.e. all suppliers other than Australia, would rise due to lower prices that

could be offered by competing exporting countries as a result of their lower cost of production. For the same reason, there would be a concordant shift from importation of processed product to raw product; currently only Australia can supply uncooked product. Since the scale of these future changes are uncertain, the model conservatively assumed that, under the proposed relaxation of import health standards, current total imports of pigmeat entering New Zealand would remain constant. The proportion of imported pigmeat expected to contain infectious PRRSV (CONTAMINATION_P) was represented in the model using a Pert distribution, with 0.003 as the minimum, 0.012 as the most likely, and 0.045 as the maximum value. These values were consistent with the range of values presented in a pigmeat import risk analysis in New Zealand (Anonymous 2006) and related scientific literature (Magar and Larochelle 2004). Data supplied by the New Zealand Pork Industry Board (NZPIB) estimated that 90% of pigmeat currently imported was being treated in a manner that was likely to kill PRRSV, allowing the variable IMPORT_PROCESS_P to be set at a point value of 0.90. At present, only Australia, which is PRRS free, can supply raw pigmeat into New Zealand. The output of Step 1, PCT_PORK_INFECTED, or the proportion of all pork consumed in New Zealand that contains infectious PRRSV, was calculated using the following equation:

(Equation 1)
CONTAMINATION_P * IMPORT_PCT * (1-IMPORT_PROCESS_P)

Step 2. Estimate of the number of premises that own pigs and feed potentially infected food waste

Step 2 in the assessment estimated the number of premises that owned pigs and fed uncooked waste food to their animals; knowledge of four parameters was required to make the calculation. New Zealand previously had audited procedures that only permitted the feeding of cooked food waste to pigs but in 1998, these regulations were allowed to lapse. From 1999 to 2005, feeding of uncooked waste food from homes and food-service establishments to pigs was legal. In 2005, the requirement for cooking was re-instituted but awareness of and compliance with the regulations in this segment of the population is currently considered to be low. Since 2001, pigmeat imported into New Zealand from PRRS-infected countries must be cooked in a transitional import facility, to inactivate PRRSV; proposals have recently been made by the Ministry of Agriculture

and Forestry to remove the cooking requirement for imported pigmeat that is delivered in the form of a ‘high-value cut’.

The variable TOT_PIGPREMISES represented the total number of premises in New Zealand that owned one or more pigs at any given point in time. The non- and para-commercial sectors of the pig industry in New Zealand include a substantial number of small-holder premises raising pigs for consumption or hobby. The commercial pig industry in New Zealand comprises approximately 300 herds, and only a single registered commercial farm is currently known to practise waste-food feeding. However, there are a large number of households in New Zealand that keep small herds or a few ‘backyard’ pigs, and feed waste from the home kitchen or from food-service establishments. Consumption of home-reared pigs is a widespread cultural practice in social events such as the ‘hangi’.

AgriBase is a national spatial farms database of non-urban areas in New Zealand that provided spatial locations and animal population estimates for over 7,000 rural properties which reported raising pigs on a non-commercial basis. There are substantial numbers of pigs which are kept in urban and peri-urban areas of New Zealand on non-agricultural holdings, and hence are excluded from AgriBase. TOT_PIGPREMISES was described using a Pert distribution that included 7,000 premises as the minimum value (data provided by AgriBase), 12,000 as the most likely value (to include an estimated 5,000 premises which keep pigs in urban and peri-urban areas), and 20,000 as the maximum in order to capture a point-in-time estimate that included all premises that kept pigs intermittently during the year.

Data on consumption of pigmeat in New Zealand were available only at the level of a ‘New Zealand household’. For the purposes of this model, a ‘household’ was considered to be equivalent to a ‘premises’. As over 90% of pig-holdings in New Zealand were non- or para-commercial, these herds were considered as potential feeders of food waste. The WASTEFEEDING_P variable represented the prevalence of food-waste feeding across all pigholdings, and was described by a normal distribution centred at 0.80. The proportion of waste-feeding premises that allowed inclusion of raw pigmeat in pig feed was represented by a variable called MEATFEEDING_P, and was set at 20%. Finally, the degree of compliance amongst this group of waste-food feeders regarding the regulatory requirement to cook meat-containing waste food at 100°C for one hour (COMPLIANCE_P) was estimated to be 10%. The output of Step 2,

TOT_NUM_WASTEFEEDERS, or the total number of NZ pig-owning premises that fed raw meat waste to their pigs, was calculated using the following equation:

(Equation 2)
TOT_PIGPREMISES * WASTEFEEDING_P * MEATFEEDING_P*(1-COMPLIANCE_P)

Step 3. Estimate of the volume of food waste generated by households in New Zealand
Step 3 in the risk model estimated the volume of pigmeat-containing food waste generated by a typical household in New Zealand. The NZPIB provided pigmeat (fresh, not including ham or bacon) consumption data for 2005, collected through their pork-marketing activities. Their marketing data were collected through personal interview of a sample of representative households in New Zealand, including both families that ate pork and those that did not; the data collection and sampling procedure were administered by a professional marketing agency. Data on pork consumption were collected by asking survey participants 'how many times per month does your family eat pork?' The survey reported that 61% of households consumed a pork meal on at least one occasion per month. This was comprised of 17% of families that consumed pork once a month, 17% that consumed pork twice per month, 11% that consumed pork three times per month, 7% that consumed pork four times per month, and 9% that consumed pork five or more times per month. This consumption information was used to populate two model variables, PORK_CONS_PREMISES (the proportion of premises in New Zealand that consumed a pork meal at least once a month), and PREMISES_FREQ (the number of pork meals consumed annually by each pork-consuming household). A Pert distribution was used to model PORK_CONS_PREMISES, and the most likely value was estimated to be 61%, the minimum value 50%, and the maximum value 80%. The positive skew in this distribution represented the belief that those households owning pigs were more likely to be pork consumers than the average household in New Zealand. A truncated normal distribution was created to represent the monthly consumption pattern of pork for those households that declared themselves to be consumers of pork. By truncating the minimum value for a normal distribution to one meal per household per month and the maximum to 11, a mean value of 2.3 pork meals (standard deviation 2.0) per month was produced, and both total consumption and the consumption pattern of pork reported in

the NZPIB market survey were well-described. To aggregate these monthly estimates to represent yearly consumption of pork, the randomly selected PORK_CONS_PREMISES variable used in each model simulation was multiplied by a factor of 12. The remaining variable in this step accounted for the likelihood that pig-owning households would be consuming at least some pork harvested from their own pig(s) and thus would have less need to purchase fresh pork, that would potentially contain PRRSV. The proportion of pork meals that were comprised of purchased pork vs home-raised pork for those families that raised pigs (PIGPREMISE_BUYPORK_P) was estimated to be 25%. The output of Step 3, TOT_NUM_ PORKMEALS, or the total number of pork meals consumed in New Zealand per year that were prepared using purchased pork (by those 'pork-eating' households that also owned pigs), was calculated using the following equation:

(Equation 3)
TOT_NUM_WASTEFEEDERS * PORK_CONS_PREMISES * PREMISES_FREQ * PIGPREMISE_BUYPORK_P

Step 4. Estimate of the likelihood that feeding food waste would result in PRRSV infection

Step 4 in the exposure assessment estimated the likelihood of a pork-containing meal generating a meat scrap that contained enough PRRSV to successfully infect at least one pig on a waste food-feeding premises. Data to support the assumptions in this compartment came from the NZPIB pork consumption study referred to above, expert opinion, and citations from publications listed above. The first variable in this step, PORK_PER_MEAL, represented the total amount (kg) of fresh pork prepared for a pork meal in an average household. Data from NZPIB reported two distinct values for pork consumption: 125 g raw pork per average serving (Mackay 1999) and 1,250 g raw pork per typical family meal, calculated by dividing the total consumption of fresh pork in New Zealand by the estimated total number of family meals per year. This same pork consumption study indicated the average household size in the survey included 2.6 people. This information was represented by constructing a Pert distribution with a most likely value of 325 g (2.6 people multiplied by an average serving size of 125 g), a minimum value of 125 g (one average serving), and a maximum of 2,000 g (a large family meal). The second variable in this Step, RAW_MEAT_ SCRAP_P, was the

proportion of fresh pork in a pork meal that ended up as raw-meat waste (pre-cooking waste, trim, out-of-date). Accurate data to describe the proportion of waste that is comprised of raw meat are sparse. A study in 2002 in Singapore estimated 4% of household rubbish was comprised of meat (Hwang et al 2002). Another study describing the risks to farm animals from pathogens in composted catering waste containing meat reported three estimates of the amount of uncooked meat discarded (Gale 2004), and ranged from 0.94 to 3.5%. A recent study of the waste stream from small- and medium-sized business enterprises in England indicated that 45% of the waste stream was comprised of food and kitchen waste (Thomas et al 2007). Approximately half of this amount was classified as containing meat. A report in 2004 on the composition of waste in the United Kingdom cited six studies that reported 20.44% of household waste was comprised of 'putrescibles' but provided no specific details on meat waste (Anonymous 2004a). A 2007 study cited data from domestic surveys conducted in Great Britain that estimated between 5 and 15% of purchased meat was disposed; the amount of meat disposed that was cooked vs raw was not stated (Hartnett et al 2007). In general, volume or weight estimates of raw meat as a component of household waste are poorly described but have been reported across a range of 1 to 15%. For this exposure assessment, a point estimate of 0.10 was utilised; sensitivity of the entire model to this variable was explored, and is reported in the Results section. The output of Step 4, P_SCRAP_INFECTIOUS, or the probability that a pork-containing meal would generate scrap capable of infecting a pig, was calculated using the following equation:

(Equation 4)
PORK_PER_MEAL * RAW_MEAT_SCRAP_P

For estimated scrap sizes <0.02 kg the probability of containing an infectious dose of PRRSV was set to 0.10 and for estimated scrap sizes ≥0.02 kg the probability of containing an infectious dose of PRRSV was set to 0.63.
By including the logic statements for the value of P_SCRAP_INFECTIOUS, the model compartmentalised the risk associated with feeding raw pork scraps. If total meat scrap weight per household meal was <20 g then the likelihood of infection occurring was set at 10%. For total scrap weights ≥20 g, infectivity was set at 63%, which is consistent with studies reported previously (Magar and Larochelle 2004; Cano et al 2007).

Step 5. Estimate of the expected number of PRRSV-infected premises annually

Step 5 in the exposure assessment estimated the expected number of PRRSV-infected premises annually, based on output from Steps 1, 3, and 4. The product of the proportion of all pork consumed in New Zealand that contained infectious PRRSV (PCT_PORK_INFECTED), the number of pork meals consumed per year in New Zealand and prepared by those households that both raised pigs and consumed purchased pork (TOT_NUM_PORKMEALS), and the probability that those meals would generate meat waste of sufficient size to infect a pig (P_SCRAP_INFECTIOUS) yielded the estimated number of households that would be expected to have their pigs become infected with PRRSV per year. The following equation shows this calculation:

(Equation 5)

PCT_PORK_INFECTED * TOT_NUM_PORKMEALS * P_SCRAP_INFECTIOUS

Consequence assessment

Output from the exposure assessment provided an estimate of the annual frequency with which PRRSV would be expected to become established in a pig herd(s) in New Zealand. To determine the likelihood that infection of the initial herd would be spread to other herds, a computer simulation model was developed using InterSpread Plus software (InterSpread Plus, EpiCentre, Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Palmerston North, NZ).

InterSpread Plus is a computer program for modelling the spread of infectious disease amongst animal populations. The software functions as a state transition model (Isham 1993), meaning that the units of interest (farm locations) exist in one of several states at any time. Classical approaches to state transition modelling consider the population at risk only in terms of the number of population units which exist in each state at given time periods, and use differential equations to estimate the turnover of populations between one state and another (Anderson and May 1991). Within InterSpread Plus, population units (farm locations) are individually defined based on their physical location within a region, then through use of Monte Carlo simulation techniques the dynamics of infection and disease are simulated through daily cycles. The key advantage of this approach is that a higher degree of biological realism can be achieved in representing the behaviour of the disease in a real-world population.

A central data requirement when using InterSpread Plus to model an actual country or region is that the user must provide an explicit spatial description of the population of herds at risk. Cartesian coordinates are used to define the locations of members of the population at risk; they can be specified as either discrete polygonal units or as points (typically the position of the farm centroid). These populations are also defined by species and the farm class type, e.g. 'commercial farrow-to-finish', 'commercial genetic stock supplier', and 'para-commercial farrow-to-weaner'. Once defined, parameters can be associated with these farm classes, allowing their specific behaviours to be characterised within the model. For example, regular, short-distance movement patterns might be parameterised for locations with a 'dairy' descriptor whereas infrequent, longer-distance movement patterns might be specified for those described as 'beef breeding'. The model also allows identification of non-farm locations that function as regular or intermittent livestock co-mingling site, e.g. saleyards, exhibitions, abattoirs. Historical and experimental evidence assists the modeller in defining the relative importance (probability and frequency) of disease transmission through combinations of animal movement, and fomite, local, and airborne spread. Whether or not a change in state occurs during any day-step of the model is determined through sampling from user-defined probability distributions at each step in the pathway making the process stochastic. Multiple iterations of a model are then undertaken to generate a distribution of predicted outcomes rather than a single number. In practical terms, this allows decision makers to distinguish between strategies that are highly predictable, i.e. the variance of the predicted outcomes is small, and strategies that are less predictable, i.e. those where the variance of predicted outcomes is large.

The model was initially populated using the actual spatial location of all known pig-holdings in non-urban areas of New Zealand. To represent non-commercial pig-holdings in peri-urban areas, 5,000 additional small pig herds were created and randomly placed in specific regions of the country where such herds are believed to be numerous (2,500 herds within a 50-km radius of Auckland Central Business District; 1,000 herds within a 20-km radius of Christchurch; and 500 herds each within a 20-km radius of Hamilton, Dunedin, and Palmerston North). In order to characterise the movement behaviour of various types of pig herds, each herd was placed into a FARM CLASS, using criteria detailed in Table 6 on Page 114.

Parameterisation of the model

InterSpread Plus models transmission at the herd level and does not individually consider the dynamics of within-herd spread of disease. The risk of transmission associated with exposure is specified by the probability of transmission (POT) parameter for each movement type, and also by the matrix of probability by time and distance in the local spread mechanism. The infectivity parameter represents the relative likelihood of a herd remaining contagious over time, and serves to moderate the specific POTs defined for each transmission mechanism.

Parameters used in modelling potential epidemics of PRRS in New Zealand included the frequency of direct movements of pigs amongst FARM CLASSes and probabilities of moving different distances, indirect movements of pigs amongst FARM CLASSes through saleyards, local spread over a distance up to one km (between animals on contiguous premises, short-distance aerosol, rodent and insect vectors, other undetermined mechanisms), and infectivity.

Direct movements of pigs were parameterised to emphasise the likely frequent movements amongst non- and para-commercial herds, the known frequent movements from commercial breeding herds to commercial finishers, and the known frequent movements from genetic suppliers to commercial breeding herds. Other movement types were given low probabilities because they were believed to be relatively infrequent. A matrix of parameter settings related to direct movement of pigs amongst herds is shown in Table 7 on Page 115.

Modelling of disease spread as a result of movement of infected pigs through saleyards required estimation of four different model parameters: the proportion and the frequency of total movements to saleyards that originated from each FARM CLASS, the distribution of the number of herds receiving movements of pigs from a saleyard per movement to the saleyard, and the probability of disease transmission through saleyard-associated movements of pigs. The components of pig movement through saleyards are described in Table 8 on Page 116, and show the overall low reliance of the pig industry in New Zealand on saleyard trading. However, those movements associated with saleyards were almost entirely attributed to non- and para-commercial herds. The relative magnitude of the number of movements into saleyards compared with movements out of saleyards was described using a Poisson(2) distribution.

The distance over which movements of pigs occurred was an important component in determining the geographical extent of an outbreak. InterSpread Plus allows

construction of matrices that described the relationship between various distances travelled and the proportion of movements that occurred at each distance. In the case of movements of pigs amongst FARM CLASSes, just over 50% of movements were estimated to occur at ≤40 km. The distances associated with movements both to and from saleyards were allowed to extend up to 200 km, but more than 85% of movements were estimated to occur at ≤50 km. A full description of the movement distance matrices is presented in Table 9 on Page 117. Values for these movements were based on expert opinion, influenced by experience in providing veterinary services to the pig industry, investigating various pig disease outbreaks in New Zealand, and specific studies of animal movement patterns (Sanson et al 1993; Sanson 2005).

Two additional parameters were utilised that were specific to PRRSV rather than the structure of the pig industry in New Zealand: the likelihood that a herd was contagious at given time periods post-infection, and the likelihood of local spread to nearby herds, i.e. in the absence of direct contact with a pig. PRRSV infection is known to persist for extended periods in the tissues of infected pigs. However, these same pigs are known to become less contagious over time. Non-commercial herds were modelled by temporally decreasing their level of infectivity until 150 days post-infection, at which point they were no longer considered contagious, and not considered susceptible to reinfection within the run time of the model; the larger para-commercial herds followed a similar decreasing infectivity but only became non-contagious after 250 days post-infection. Once they became infected, commercial herds, being larger and more likely to be routinely introducing naïve replacement breeding animals, were considered 'actively infected' and contagious until the end of the model run (Table 10, Page 118). The likelihood of infection being transmitted from an infected herd to each of the herds within a one to two km radius of its centre was set at 0.04% per day. This value is based on estimates of local spread derived for other highly contagious diseases stated in a form suitable for use in InterSpread Plus; no quantitative data specific for PRRS could be located to test the suitability of this value. InterSpread Plus was capable of modelling aerosol transmission as a separate means of PRRSV spread. While this mechanism of transmission has been demonstrated with PRRSV, its relative importance for transmission beyond the local spread zone (one to two km) remains unresolved, so it was not used in the described simulations.

Model simulations

For each simulation, infection was initiated in a single, randomly chosen non-commercial herd, and subsequent daily changes in the state of the herd were modelled for either one- or three-year periods. One hundred iterations of the one-year simulation and 20 iterations of the three-year simulation were run using the parameter values described.

Results

Exposure assessment

The exposure assessment was modelled using 1,000 simulations and Latin Hypercube sampling. A range of simulations (500, 1000, 5000, and 10000) were conducted; at 1,000 the median value of the model output changed by no more than 2.5% between model runs suggesting there was no additional benefit in running more than the specified 1,000 simulations. The distribution of outputs indicated that a mean of 4.30 premises would become infected per year as a result of exposure to the virus through feeding of food waste. The median number of infected premises in the same model was 3.27; a long right-hand tail gave a low probability that up to 31 premises would become infected per year. In 9.7% of iterations, no herds became infected. A complete summary of model outputs providing percentile breakdowns and a histogram of the proportion of simulations that resulted in various numbers of infected premises is provided in Table 11 on Page 119.

Sensitivity analysis

Five variables were independently changed over a biologically appropriate range around the initial setting, to measure their incremental effect on the 5th, 50th, and 95th percentile values of the expected number of premises that would become infected with PRRSV each year. The model output was relatively insensitive to 25–100% changes in parameter values for the proportion of pork consumed in New Zealand that would be imported from a PRRS affected country, the proportion of waste-food-feeding premises that cooked food waste sufficiently to kill PRRSV, the proportion of fresh pork in a meal that ended up as raw meat waste, and the proportion of imported pork expected to contain a contagious amount of PRRSV. For each of these parameters, varying the values across the described range only changed the median number of infected herds by about one or two herds per year. The proportion of fresh pork in a meal that ended up as raw meat waste had to be set below 3.3%, in order to bring the median number of herds infected annually to below 1. However, increasing or decreasing the proportion of

imported pork expected to be processed in a manner that would kill PRRSV by only 10% changed the expected median number of infected herds by more than three herds per year, representing a nearly 200% change from the base model settings.

The initial parameter settings for the exposure assessment model were meant to represent a conservative view of the magnitude of contaminated meat entering New Zealand and the extent and nature of waste-food feeding in the pig industry. In addition to this model, a second version of the model was constructed using a set of parameters that presented a more risk-averse perspective on the future importation of contaminated meat, and the habits of those pig owners in New Zealand who fed waste food. This model decreased the proportion of imported pork expected to be processed in a manner that would kill PRRSV from a point estimate of 0.90 to a probability distribution defined by Pert(0.60, 0.75, 0.90), increased the proportion of households in New Zealand that consumed a pork meal at least once a month from Pert(0.50, 0.61, 0.80) to Pert(0.50, 0.61, 0.90), and increased the proportion of purchased (vs home-butchered) pork that made up a pork meal consumed by pig-owning households to 60%. The net effect of these changes was an increase in the mean number of infected premises to 26.18 (median 19.84, 95th percentile 70.76) per year. Only 0.2% of the iterations resulted in no infected premises.

Consequence assessment

Using the base parameter settings as described, both the one- and three-year simulations showed that PRRSV infection would spread steadily following introduction. In 64% of one-year simulations and in 65% of three-year simulations, the infection failed to spread beyond the initial herd even without control measures being applied. However, of the outbreaks that did extend beyond the initial herd, a mean of 93 herds, including those simulations that resulted in no spread, became infected within one year, and a mean of 587 herds became infected within three years of the initial herd becoming infected. When results were averaged across all runs, the mean number of herds infected after one year was 34 and after three years was 66. A graph of the cumulative number of infected herds is shown in Figure 11 on Page 122. In this figure, the variability around the median value for a given day in the outbreak is described by standard deviation; the lower standard deviation is truncated at zero as a negative number of infected herds would be nonsensical. The distribution of outputs that described the predicted total number of outbreaks for both the one- and three-year periods had extended right-hand

tails; one of the three-year iterations resulted in more than 5,000 premises becoming infected.

In 8% of simulations, even when the initial infection occurred in a random non-commercial herd, the model predicted that a PRRS outbreak would reach the commercial pig industry within one year.

Sensitivity analysis

The infectivity parameter was modified such that all non- and para-commercial herds would remain fully contagious for up to 250 days following infection with PRRSV, while commercial herds remained continuously infectious. Beyond Day 250 post-infection, non- and para-commercial herds continued to be considered 'infected' but were no longer capable of infecting other herds. This modification allowed creation of a distribution of outputs that was more likely to be relevant for disease response planning than that of the base model. The net effect of the change in the infectivity pattern was to increase the mean number of herds infected at one year to 205 (including those iterations that resulted in no transmission to secondary herds), and 39% of simulations resulted in infected pig herds in the commercial sector. Within three years, an average of 2,396 herds was predicted to become infected, and 65% of runs affected the commercial industry.

Discussion

Data provided in a recently completed risk analysis of imported pigmeat to New Zealand suggested that PRRSV was likely to be introduced into New Zealand at the rate of 0.30–1.20 kg per tonne of raw pigmeat imported from countries endemically infected with PRRSV (Anonymous 2006). A binomial sampling approach further suggested that these levels of contamination result in a 78% likelihood of importing virus in the first 10 tonnes of pigmeat. The annual volume of imported pigmeat was reported in 2004 to be approximately 25,200 tonnes carcass weight equivalent, suggesting that importation of PRRSV would be inevitable if raw pigmeat was imported on a substantial scale. Accepting that PRRSV is likely to arrive in the country, the exposure assessment modelling, even when using conservative parameter estimates, predicted that pig(s) on an average of 4.3 premises per year would become infected.

Given a mean of 4.3 infected premises per year and a 36% probability of infection spreading beyond the initial herd, there was a 95% likelihood of a multi-herd PRRS outbreak occurring within 3 years (=CRITBINOM(4.30,0.36,0.95); Microsoft Excel function). This calculation assumed that the incursions did not happen concurrently;

concurrent outbreaks would be expected to lead to more rapid and extensive spread through the industry.

The simulation models indicated that PRRSV spread in New Zealand would be consistent with overseas experience, in that once the disease became established in an initial herd it would become rapidly and widely established within New Zealand. The ratio of para-commercial and non-commercial herds to commercial herds is exceptionally high in New Zealand, thus increasing the susceptibility of the commercial industry to entry and establishment of PRRS through these other sectors.

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References

An TQ, Zhou YJ, Liu GQ, Tian ZJ, Li J, Qiu HJ, Tong GZ. Genetic diversity and phylogenetic analysis of glycoprotein 5 of PRRSV isolates in mainland China from 1996 to 2006: Coexistence of two NA-subgenotypes with great diversity. *Veterinary Microbiology* 123, 43-52, 2007

Anderson RM, May RM. Infectious diseases of humans: dynamics and control, Oxford University Press, Oxford ; New York, 1991

***Anonymous.** Waste Composition Analysis, Guidance for Local Authorities: Appendices. *Department for Environment, Food and Rural Affairs*, London, England, 2004a

*__Anonymous.__ Situation and Outlook for New Zealand Agriculture and Forestry 2004. http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/sonzaf/2004/2004-sonzaf-22.htm (accessed 18 October 2007). New Zealand Ministry of Agriculture and Forestry, Wellington, NZ, 2004b

*__Anonymous.__ Import Risk Analysis: Porcine Reproductive and Respiratory Syndrome (PRRS) Virus in Pig Meat. http://www.biosecurity.govt.nz/files/pests-diseases/animals/risk/prrs-ra.pdf (accessed 02 September 2007). Biosecurity New Zealand, Wellington, NZ, 2006

Cano JP, Murtaugh MP, Dee SA. Evaluation of the survival of porcine reproductive and respiratory syndrome virus in non-processed pig meat. *Veterinary Record* 160, 907-8, 2007

Collins JE, Benfield DA, Christianson WT, Harris L, Hennings JC, Shaw DP, Goyal SM, McCullough S, Morrison RB, Joo HS, et al. Isolation of swine infertility and respiratory syndrome virus (isolate ATCC VR-2332) in North America and experimental reproduction of the disease in gnotobiotic pigs. *Journal of Veterinary Diagnostic Investigation* 4, 117-26, 1992

***Daniels CS.** Area spread of PRRS virus from a small population of backyard pigs. *Proceedings of 34th Annual American Association of Swine Veterinarians Pre-conference Seminar on Preventing and Controlling PRRS: Mission Impossible?* Orlando, Florida, USA Pp 29-33, 2003

Dee S, Deen J, Rossow K, Wiese C, Otake S, Joo HS, Pijoan C. Mechanical transmission of porcine reproductive and respiratory syndrome virus throughout a coordinated sequence of events during cold weather. *Canadian Journal of Veterinary Research* 66, 232-9, 2002

Dee S, Deen J, Rossow K, Weise C, Eliason R, Otake S, Joo HS, Pijoan C. Mechanical transmission of porcine reproductive and respiratory syndrome virus throughout a coordinated sequence of events during warm weather. *Canadian Journal of Veterinary Research* 67, 12-9, 2003

Desrosiers R. Aerosol spread of the PRRS virus: why it is too early to say no. *International Pig Letter* 22, 21-3, 2002

***Desrosiers R.** Epidemiology, diagnosis and control of swine diseases. *Proceedings of 35th Annual Meeting of the American Association of Swine Veterinarians* Pp 9-38, 2004

Fang Y, Schneider P, Zhang WP, Faaberg KS, Nelson EA, Rowland RR. Diversity and evolution of a newly emerged North American Type 1 porcine arterivirus: analysis of isolates collected between 1999 and 2004. *Archives of Virology* 152, 1009-17, 2007

Gale P. Risks to farm animals from pathogens in composted catering waste containing meat. *Veterinary Record* 155, 77-82, 2004

Goldberg TL, Hahn EC, Weigel RM, Scherba G. Genetic, geographical and temporal variation of porcine reproductive and respiratory syndrome virus in Illinois. *Journal of General Virology* 81, 171-9, 2000

Hartnett E, Adkin A, Seaman M, Cooper J, Watson E, Coburn H, England T, Marooney C, Cox A, Wooldridge M. A quantitative assessment of the risks from illegally imported meat contaminated with foot and mouth disease virus to Great Britain. *Risk Analysis* 27, 187-202, 2007

Hermann JR, Munoz-Zanzi CA, Roof MB, Burkhart K, Zimmerman JJ. Probability of porcine reproductive and respiratory syndrome (PRRS) virus infection as a function of exposure route and dose. *Veterinary Microbiology* 110, 7-16, 2005

Holck JT, Polson DD. Financial Impact of PRRS. In: Zimmerman JJ, Yoon KJ (eds). *2003 PRRS Compendium*. Pp 51-7. National Pork Board, Des Moines, IA, USA, 2003

Hooper CC, Van Alstine WG, Stevenson GW, Kanitz CL. Mice and rats (laboratory and feral) are not a reservoir for PRRS virus. *Journal of Veterinary Diagnostic Investigation* 6, 13-5, 1994

Hurd S, Bush EJ, W. L, Corso B, Zimmerman JJ, Wills RW, Swenson SL, Pyburn D, Yeske P, Burkgren T. Outbreaks of porcine reproductive failure: Report on a collaborative field investigation. *Swine Health and Production* 9, 103-8, 2001

Hwang EJ, Shin HS, Tay JH. Continuous feed, on-site composting of kitchen garbage. *Waste Management and Research* 20, 119-26, 2002

Isham V. Stochastic Models for Epidemics with Special Reference to AIDS. *The Annals of Applied Probability* 3, 1-27, 1993

***Lager KM, Mengeling WL.** Experimental aerosol transmission of pseudorabies virus and porcine reproductive and respiratory syndrome virus. *Proceedings of 31st Annual Meeting of the American Association of Swine Practitioners*. Indianapolis, Indiana, USA Pp 409-10, 2000

Lager KM, Mengeling WL, Wesley RD. Evidence for local spread of porcine reproductive and respiratory syndrome virus. *Swine Health and Production* 10, 167-70, 2002

Larochelle R, D'Allaire S, Magar R. Molecular epidemiology of porcine reproductive and respiratory syndrome virus (PRRSV) in Quebec. *Virus Research* 96, 3-14, 2003

***Mackay S.** Red meat & poultry: an evidence-based nutrition statement from the National Heart Foundation of New Zealand's Nutrition Advisory Committee. http://www.nhf.org.nz/files/National%20Dietitian/Meat_March1999.pdf (accessed 19 October 2007). National Heart Foundation of New Zealand, 1999

Magar R, Larochelle R. Evaluation of the presence of porcine reproductive and respiratory syndrome virus in pig meat and experimental transmission following oral exposure. *Canadian Journal of Veterinary Research* 68, 259-66, 2004

***Mateusen B, Van Soom A, Maes DG, Nauwynck H.** Assessment of the susceptibility of porcine pre-implantation embryos to pseudorabies virus (PRV) and porcine reproductive and respiratory syndrome virus (PRRSV) using subzonal microinjection. *Proceedings of Annual Conference of the International Embryo Transfer Society*. Orlando, Florida, USA. (eds) Dobrinski I, Fayrer-Hosken RA) p 214. (Commonwealth Scientific and Industrial Research Organization), 2006

***Mohr MF, Rossow KD.** Unique porcine reproductive and respiratory syndrome (PRRSv) sequences identified in four Minnesota swine herds. *Proceedings of 45th Annual Meeting of the American Association of Veterinary Laboratory Diagnosticians* p 42, 2002

Mondaca-Fernandez E, Murtaugh MP, Morrison RB. Association between genetic sequence homology of Porcine reproductive and respiratory syndrome virus and geographic distance between pig sites. *Canadian Journal of Veterinary Research* 70, 237-9, 2006

Mondaca-Fernandez E, Morrison RB. Applying spatial analysis to a porcine reproductive and respiratory syndrome regional control programme. *Veterinary Record* 161, 137-8, 2007

Mortensen S, Stryhn H, Sogaard R, Boklund A, Stark KD, Christensen J, Willeberg P. Risk factors for infection of sow herds with porcine reproductive and respiratory syndrome (PRRS) virus. *Preventive Veterinary Medicine* 53, 83-101, 2002

Murtaugh MP, Elam MR, Kakach LT. Comparison of the structural protein coding sequences of the VR-2332 and Lelystad virus strains of the PRRS virus. *Archives of Virology* 140, 1451-60, 1995

Neumann EJ, Kliebenstein JB, Johnson CD, Mabry JW, Bush EJ, Seitzinger AH, Green AL, Zimmerman JJ. Assessment of the economic impact of porcine

reproductive and respiratory syndrome on swine production in the United States. *Journal of the American Veterinary Medical Association* 227, 385-92, 2005

Otake S, Dee SA, Jacobson L, Torremorell M, Pijoan C. Evaluation of aerosol transmission of porcine reproductive and respiratory syndrome virus under controlled field conditions. *Veterinary Record* 150, 804-8, 2002a

Otake S, Dee SA, Rossow KD. Transmission of porcine reproductive and respiratory syndrome virus by fomites (boots and coveralls). *Swine Health and Production* 10, 59-65, 2002b

Otake S, Dee SA, Rossow KD, Joo HS, Deen J, Molitor TW, Pijoan C. Transmission of porcine reproductive and respiratory syndrome virus by needles. *Veterinary Record* 150, 114-5, 2002c

Otake S, Dee SA, Rossow KD, Moon RD, Pijoan C. Mechanical transmission of porcine reproductive and respiratory syndrome virus by mosquitoes, *Aedes vexans* (Meigen). *Canadian Journal of Veterinary Research* 66, 191-5, 2002d

***Pitkin A, Dee S.** Aerosol transmission of PRRSV: Application to the field (preliminary data). *Proceedings of 38th Annual Meeting of the American Association of Swine Veterinarians*. Orlando, Florida, USA p 477, 2007

Prieto C, Suarez P, Martin-Rillo S, Simarro I, Solana A, Castro JM. Effect of porcine reproductive and respiratory syndrome virus (PRRSV) on development of porcine fertilized ova in vitro. *Theriogenology* 46, 687-93, 1996

Randall AE, Pettitt MJ, Plante C, Buckrell BC, Randall GCB, Henderson JM, Larochelle R, Magar R, Pollard JW. Elimination of porcine reproductive and respiratory syndrome virus through embryo transfer. *Theriogenology* 51, 274, 1999

Rossow KD. Porcine reproductive and respiratory syndrome. *Veterinary Pathology* 35, 1-20, 1998

Rowland RR, Lawson S, Rossow K, Benfield DA. Lymphoid tissue tropism of porcine reproductive and respiratory syndrome virus replication during persistent infection of pigs originally exposed to virus *in utero*. *Veterinary Microbiology* 96, 219-35, 2003

Sanson RL, Struthers G, King P, Weston JF, Morris RS. The potential extent of transmission of foot-and-mouth disease: a study of the movement of animals and materials in Southland, New Zealand. *New Zealand Veterinary Journal* 41, 21-8, 1993

Sanson RL. A survey to investigate movements off sheep and cattle farms in New Zealand, with reference to the potential transmission of foot-and-mouth disease. *New Zealand Veterinary Journal* 53, 223-33, 2005

Schurrer JA, Dee SA, Moon RD, Rossow KD, Mahlum C, Mondaca E, Otake S, Fano E, Collins JE, Pijoan C. Spatial dispersal of porcine reproductive and respiratory syndrome virus-contaminated flies after contact with experimentally infected pigs. *American Journal of Veterinary Research* 65, 1284-92, 2004

Schurrer JA, Dee SA, Moon RD, Murtaugh MP, Finnegan CP, Deen J, Kleiboeker SB, Pijoan CB. Retention of ingested porcine reproductive and respiratory syndrome virus in houseflies. *American Journal of Veterinary Research* 66, 1517-25, 2005

Stadejek T, Oleksiewicz MB, Potapchuk D, Podgorska K. Porcine reproductive and respiratory syndrome virus strains of exceptional diversity in eastern Europe support the definition of new genetic subtypes. *Journal of General Virology* 87, 1835-41, 2006

Swenson SL, Hill HT, Zimmerman JJ, Evans LE, Wills RW, Yoon KJ, Schwartz KJ, Althouse GC, McGinley MJ, Brevik AK. Artificial insemination of gilts with porcine reproductive and respiratory syndrome (PRRS) virus-contaminated semen. *Swine Health and Production* 2, 19-23, 1994

Terpstra C, Wensvoort G, Pol JM. Experimental reproduction of porcine epidemic abortion and respiratory syndrome (mystery swine disease) by infection with Lelystad virus: Koch's postulates fulfilled. *Veterinary Quarterly* 13, 131-6, 1991

***Thomas C, Dacombe P, Maycox A, Banks C, Khan T, Slater R.** Identification of Key Resource Streams in Commercial & Industrial Waste from Small Businesses in the Food Sector, Part 1: Main Report. *Integrated Waste Systems Research Group, The Open University*, Milton Keynes, UK, 2007

Torremorell M, Pijoan C, Janni K, Walker R, Joo HS. Airborne transmission of *Actinobacillus pleuropneumoniae* and porcine reproductive and respiratory syndrome virus in nursery pigs. *American Journal of Veterinary Research* 58, 828-32, 1997

***Torrison J, Rossow K, Olson S.** Molecular evidence of area spread of PRRS virus among neighboring swine farms. *Proceedings of International Symposium on Swine Disease Eradication*. Saint Paul, Minnesota, USA Pp 89-91, 2001

Trincado C, Dee S, Rossow K, Halvorson D, Pijoan C. Evaluation of the role of mallard ducks as vectors of porcine reproductive and respiratory syndrome virus. *Veterinary Record* 154, 233-7, 2004

van der Linden IF, van der Linde-Bril EM, Voermans JJ, van Rijn PA, Pol JM, Martin R, Steverink PJ. Oral transmission of porcine reproductive and respiratory syndrome virus by muscle of experimentally infected pigs. *Veterinary Microbiology* 97, 45-54, 2003

Wesley RD, Mengeling WL, Lager KM. Prior infection of nursery-age pigs with porcine reproductive and respiratory syndrome virus does not affect the outcome

of transmissible gastroenteritis virus challenge. *Journal of Veterinary Diagnostic Investigation* 10, 221-8, 1998

Wills RW, Zimmerman JJ, Swenson SL, Yoon KJ, Hill HT, Bundy D, McGinley MJ. Transmission of PRRSV by direct, close, or indirect contact. *Swine Health and Production* 5, 213-8, 1997a

Wills RW, Zimmerman JJ, Yoon KJ, Swenson SL, McGinley MJ, Hill HT, Platt KB, Christopher-Hennings J, Nelson EA. Porcine reproductive and respiratory syndrome virus: a persistent infection. *Veterinary Microbiology* 55, 231-40, 1997b

Wills RW, Doster AR, Galeota JA, Sur JH, Osorio FA. Duration of infection and proportion of pigs persistently infected with porcine reproductive and respiratory syndrome virus. *Journal of Clinical Microbiology* 41, 58-62, 2003

Yaeger MJ, Prieve T, Collins JE, Christopher-Hennings J, Nelson E, Benfield DA. Evidence for the transmission of porcine reproductive and respiratory syndrome (PRRS) virus in boar semen. *Swine Health and Production* 1, 7-9, 1993

Yoon KJ, Joo HS, Christianson WT, Morrison RB, Dial GD. Persistent and contact infection in nursery pigs experimentally infected with porcine reproductive and respiratory syndrome (PRRS) virus. *Swine Health and Production* 1, 5-8, 1993

Zimmerman JJ, Yoon KJ, Pirtle EC, Wills RW, Sanderson TJ, McGinley MJ. Studies of porcine reproductive and respiratory syndrome (PRRS) virus infection in avian species. *Veterinary Microbiology* 55, 329-36, 1997

Tables

Table 5. Variables and parameter settings used in an exposure assessment model of porcine reproducti (PRRS) virus (PRRSV) in New Zealand (NZ). Shaded rows indicate calculated variables that determin 5.

Variable name	Description	Parameter
IMPORT_PCT	Proportion of pork consumed in NZ that will be imported from a PRRS-affected country	0.42
CONTAMINATION_P	Proportion of imported pork expected to contain a contagious amount of PRRSV	RiskPert(0.
IMPORT_PROCESS_P	Proportion of imported pork expected to be processed in a manner that would kill PRRSV	0.90
PCT_PORK_INFECTED	Proportion of all pork consumed in NZ that contains infectious PRRSV	CONTAM IMPORT_
TOT_PIGPREMISES	Total number of NZ premises (= households) that own a pig(s) at any given time	RiskPert(7(
WASTEFEEDING_P	Proportion of TOT_PIGPREMISES that feed waste food to their pigs	RiskNorma
MEATFEEDING_P	Proportion of WASTEFEEDING_P that feed waste food containing raw pork to their pigs	0.2
COMPLIANCE_P	Proportion of MEATFEEDING_P that cook food waste sufficiently to kill PRRSV	0.1
TOT_NUM_WASTEFEEDERS	Total number of NZ pig-owning premises that feed raw meat waste to their pigs	TOT_PIGP MEATFEE
PORK_CONS_PREMISES	Proportion of NZ premises (= households) that consume a pork meal at least once a month	RiskPert(0.
PREMISES_FREQ	Number of pork meals consumed annually by each PORK_CONS_PREMISES	RiskNorma
PIGPREMISE_BUYPORK_P	Proportion of pork meals consumed by PORK_CONS_PREMISES that are comprised of purchased (*vs* home-butchered) pork	0.25
TOT_NUM_PORKMEALS	Number of pork meals consumed per year in NZ that were prepared using purchased pork (by those 'pork-eating' households that also own pigs)	TOT_NUM PORK_CO PIGPREM
PORK_PER_MEAL	Kilograms of fresh pork prepared for an average household pork meal	RiskPert(0.
RAW_MEAT_SCRAP_P	Proportion of fresh pork in meal that ends up as raw meat waste	0.1
P_SCRAP_INFECTIOUS	Probability that a pork-containing meal will generate a scrap capable of infecting a pig	PORK_PE p (infectiou
		p (infectiou
NUM_INF_FARMS	Annual number of PRRSV primary infections	PCT_PORI P_SCRAP

Table 6. Description of farm classification system (FARM CLASS) based on known or assigned charac premises.

FARM CLASS	Description
Commercial farrow-to-finish	Self-identified, breeding sows and growing pigs
Commercial farrow-to-weaner	Self-identified, breeding sows but selling most pigs at time of
Commercial finisher	Self-identified, only growing pigs
Commercial genetic supplier	Self-identified, selling genetic stock or semen
Para-commercial farrow-to-weaner	Assigned, owning either more than 5 breeding sows OR more
Para-commercial other	Assigned, owning fewer than 5 breeding sows
Speciality	Assigned, owning 1–5 breeding sows of heirloom genetics
Non-commercial	Assigned, undisclosed pig inventory but confirmed not to be c
Total	

Table 7. Percentage of pig movements amongst different FARM CLASSes based on the total number o pigs involved in each movement were not considered.

	Destination						
Origin	**Comm[a]**	**Comm f–f**	**Comm f–w**	**Comm f**	**P-comm. f–w**	**P-comm. other**	**Speciality**
Comm	0	50	40	0	5	5	0
Comm f–f	0	25	15	50	5	5	0
Comm f–w	0	10	5	70	5	5	0
Comm f	0	0	40	30	0	15	0
P-comm. f–w	0	0	0	20	10	50	5
P-comm. other	0	0	0	0	10	40	20
Speciality	0	0	0	0	20	20	30
Non-comm	0	0	0	0	10	30	10

[a] Percent of total movements from each respective FARM CLASS
[b] Each row totals 100 percent of movements from that FARM CLASS
Comm = commercial; Comm f–f = commercial farrow-to-finish; Comm f–w = commercial farrow-to-weaner; Comm f = commerci to-weaner; Non-comm = non-commercial

Table 8. Percentage of pig movements amongst different FARM CLASSes that occurred through a sale the total number of movement events irrespective of the number of pigs involved in each movement eve

	Destination							
Origin	**Comm**	**Comm f–f**	**Comm f–w**	**Comm f**	**P-comm. f–w**	**P-comm. other**	**Speciality**	**Non-**
Comm	0	0	0	0	0	0	0	
Comm f–f	0	0.1	0	0.2	10	25	4.7	0
Comm f–w	0	0.1	0	0.2	10	25	4.7	0
Comm f	0	0.1	0	0.2	10	25	4.7	0
P-comm. f–w	0	0.1	0	0.2	10	25	4.7	0
P-comm. other	0	0.1	0	0.2	10	25	4.7	0
Speciality	0	0.1	0	0.2	10	25	4.7	0
Non-comm	0	0.1	0	0.2	10	25	4.7	0

Comm = commercial; Comm f–f = commercial farrow-to-finish; Comm f–w = commercial farrow-to-weaner; Comm f = commerci commercial farrow-to-weaner; Non-comm = non-commercial

Table 9. Matrix describing the percentage of movements of pigs amongst FARM CLASSes that occur a

	Euclidean one-way movement distanc									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Direct pig movements amongst FARM CLASSes	0.06	0.15	0.09	0.21	0.09	0.06	0.02	0.04	0.02	0.02
Indirect movement of pigs amongst FARM CLASSes occurring through saleyards	N/A	0.35	N/A	N/A	0.50	N/A	N/A	N/A	N/A	N/A

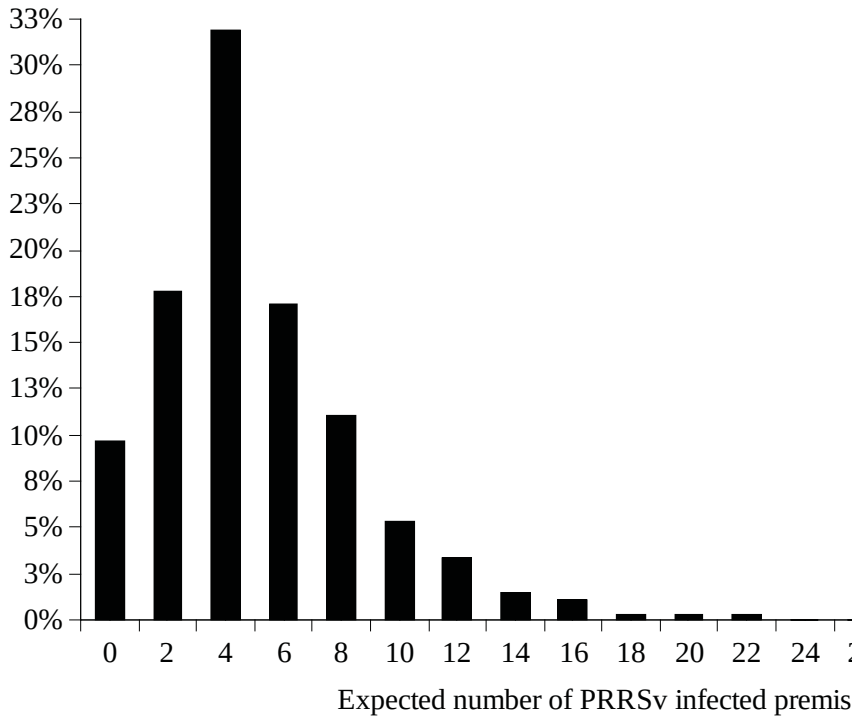
N/A = not applicable

Table 10. Likelihood of between-farm porcine reproductive and respiratory syndrome virus transmissi movement of a pig from a known infected farm to a non-infected farm.

	Farm-level infectivity during the post-infection period (days)								
Farm category	**0**	**5**	**30**	**60**	**90**	**120**	**150**	**220**	**250**
Commercial herds	0	1	1	1	1	1	1	1	1
Para-commercial herds	0	1	1	0.50	0.38	0.25	0.25	0.25	0
Non-commercial herds	0	1	1	0.50	0.38	0.25	0	0	0

Table 11. Frequency distribution of the percentage of exposure assessment model runs describing the t reproductive and respiratory syndrome virus (PRRSV)-infected premises expected to occur each year a containing PRRSV-contaminated pigmeat.

Percentile	Expected no. of infected premises/year
0	0.13
5th	0.55
25th	1.89
50th	3.27
75th	5.81
95th	11.16
1	30.70
Mean	**4.30**



Figures

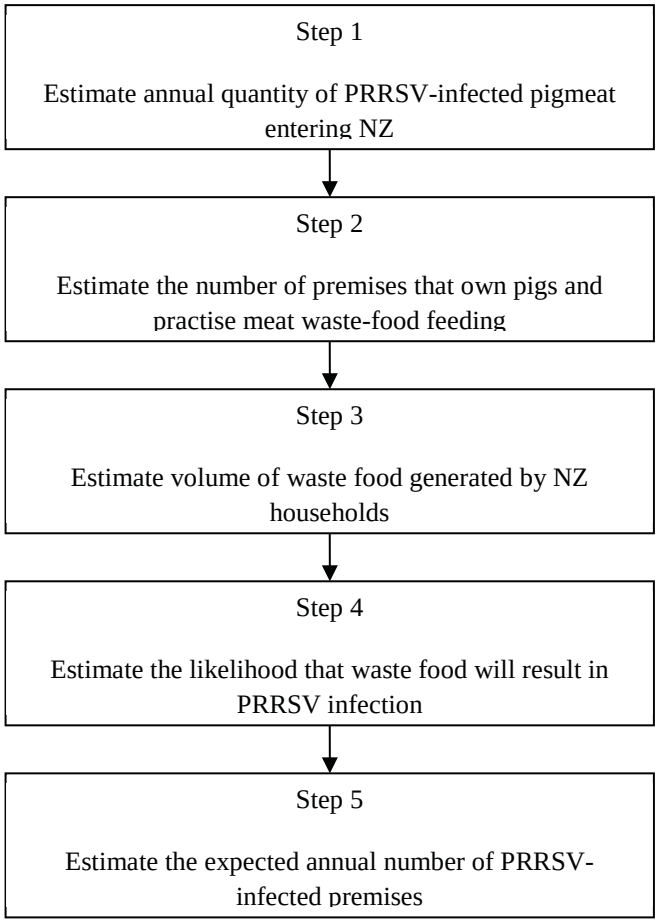


Figure 10. Compartments describing the major steps in determining the frequency of porcine reproductive and respiratory syndrome virus (PRRSV) exposure in pigs in New Zealand (NZ) as a result of feeding waste food containing pigmeat.

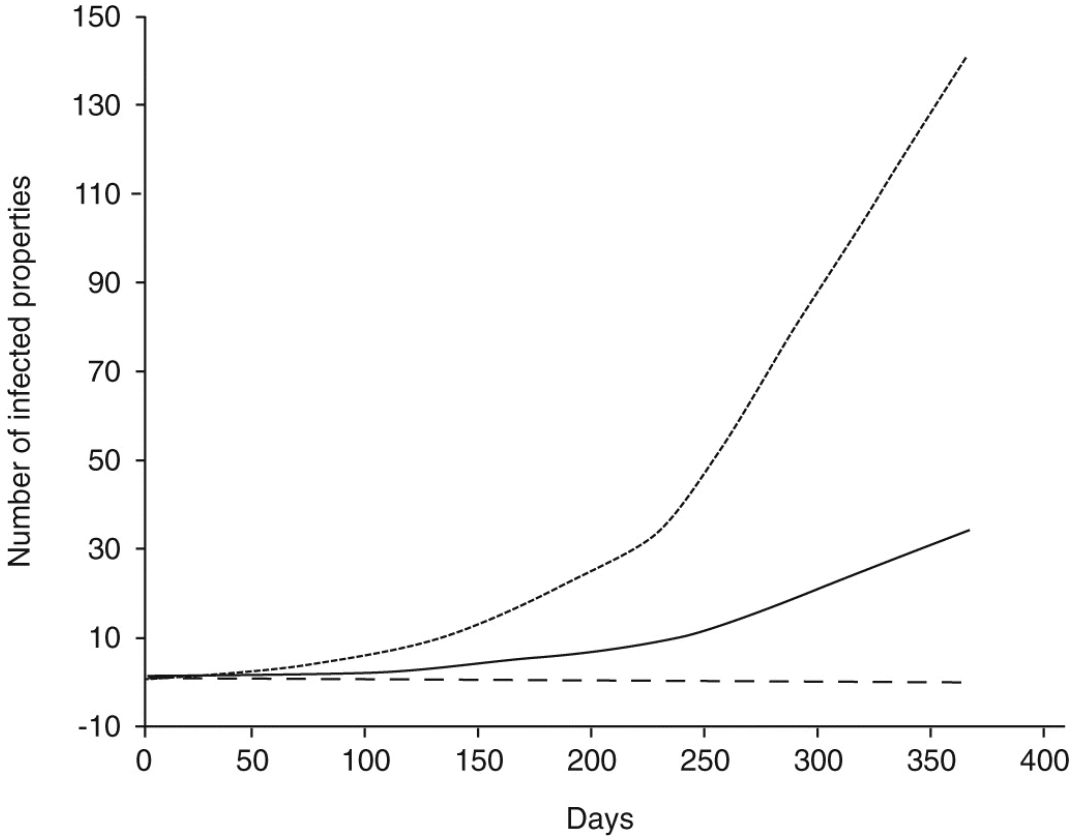


Figure 11. Cumulative number of the mean (solid), mean minus standard deviation (SD) (large dashes), and mean plus SD (small dashes) porcine reproductive and respiratory syndrome virus-infected pig farms by day of epidemic. Values represent the mean number of infected premises per day averaged across 100 iterations of a one-year simulated outbreak.

Chapter 4. The frequency and distance of movements of pigs and semen between commercial and non-commercial piggeries in New Zealand

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Abstract

AIMS: The study was conducted to identify movement patterns of disease conveyors in the New Zealand pig industry. The principal objective of the study was to identify data relating to the frequency and distance of movements of pigs and semen amongst pig holdings. A secondary objective of the study was to generate criteria suitable for categorisation of different pig breeding or raising operations.

METHODS: Prospective data were collected by a census of all known pig holdings in New Zealand using a mailed-out questionnaire.

RESULTS: The survey yielded 1,477 responses (114 commercial and 1,363 non-commercial pig holdings) for descriptive analysis. Seven farm-types were created to describe typical pig holdings and were based on pig herd inventory, herd type, and participation in the movement of pigs or semen: Commercial genetic supplier, commercial feeder, commercial weaner producer, para-commercial genetic supplier, para-commercial feeder, para-commercial weaner producer, and non-commercial herd. The farm-type with the highest frequency of movements off the piggery was the para-commercial genetic suppliers with a median of 5.3 movements off per month. Commercial feeders had the second highest off farm movement with a median of 4.6 movements per month; these primarily represented movements to an abattoir. The highest frequencies of movements on to a piggery were experienced by commercial genetic suppliers (3.5 per month) and were due to the delivery of semen or replacement gilt/boars. Para-commercial and non-commercial farm-types reported less frequent movement activities both onto and off the piggery compared to their commercial counterparts. Most movements of pigs and semen occurred over distances of less than 100 km.

CONCLUSIONS: The study showed that New Zealand has a relatively small but widely dispersed commercial pig industry with a large number of non-commercial pig holdings and there was a substantial geographic overlap between these industry sectors. Knowledge of the frequency of movements of pigs and semen among different pig farm-types and the distance over which these movements occur helps to assess the likely connectivity between piggeries, abattoirs, and sale yards. However, the study also highlighted the knowledge deficiencies that result in the absence of mandatory livestock identification and tracking schemes.

CLINICAL RELEVANCE: In an industry with substantially more non-commercial pig holdings than commercial pig-holdings, key issues such as biosecurity education,

ensuring sufficient veterinary involvement in non-commercial sectors, and building robust systems to ensure border security will remain critical in the effort to keep the pig industry at its current level of high health.

KEY WORDS: Pig, Epidemiology, Infectious disease transmission, Biosecurity, Semen

Abbreviations

MAF	Ministry of Agriculture and Forestry
NZ Pork	New Zealand Pork Industry Board

Introduction

The New Zealand pig industry benefits from the absence of many viral pathogens such as porcine reproductive and respiratory syndrome virus, transmissible gastroenteritis, and classical swine fever, which are common in much of the rest of the world (Anonymous 2012). Any incursion of new pathogens into the industry would have negative financial and animal welfare consequences for New Zealand piggeries, and would potentially jeopardise pig meat export marketing opportunities. Additionally, whilst the scale of the pig industry in the country is relatively small compared to the large dairy and sheep industries, pigs can be an important disease indicator species. This is particularly important in relation to the occurrence of some exotic livestock diseases including foot and mouth disease, which are known to affect both pigs and ruminants.

The New Zealand commercial pig industry is comprised of approximately 300 piggeries of varying size and type of operation. Commercial piggeries with breeding herds have a median of 128 sows (range=1 to 3,600) with a median total herd inventory of 710 pigs (range=1 to 28,720) based on information held in AgriBase (AsureQuality, Auckland, NZ), a spatial and demographic census of all known New Zealand farms (livestock and crop) (Sanson and Pearson 1997). The industry is primarily made up of single-site owner-operators, with limited involvement in large-scale multi-site production, contracting, and genetic production pyramids as found in other countries such as the United States (Kliebenstein and Lawrence 1995).

Given the direct consequences of an incursion of an exotic pig disease to the industry and the further consequences of pigs' potential to act as a transmission vector for exotic diseases that affect ruminant species, knowledge of the pig industry's geographical distribution and movement patterns is critically important for the development of comprehensive animal disease surveillance and response plans for New Zealand livestock.

New Zealand has a robust, but poorly described, non-commercial pig raising industry that is thought to operate largely outside normal commerce streams. This non-commercial sector of the industry periodically intersects with the commercial industry through the purchase of feed, veterinary supplies, semen, farm services, use of some abattoir facilities, and trading at livestock markets. In the event of an exotic disease incursion (or novel disease emergence) in any sector of the pig industry, sufficient information does not currently exist to accurately determine the likelihood of spread within or between the two industry streams. Disease transmission between piggeries can

occur through many previously identified routes including direct contact between animals or semen (Yaeger et al 1993), aerosolisation (Dee et al 2005), and animal contact with contaminated inanimate vectors (Otake et al 2002). Knowledge about the frequency of these kinds of interactions is important for the creation of accurate and reliable computerised disease outbreak models the outputs of which are used by animal health officials for national disease outbreak response planning.

The study was conducted to identify movement patterns of disease conveyors in the New Zealand pig industry. The principal objectives of the study were to identify the movement patterns of potentially important disease conveyors amongst pig holdings in New Zealand and to determine the extent of direct and indirect interactions within and between the commercial and non-commercial pig sectors of the New Zealand pig industry. In order to support the on-going use of disease transmission models for exotic disease response planning, a secondary objective of the study was to generate 'farm-type' criteria suitable for categorisation of different pig raising operations. Farm-type is an important input for parameterisation in disease simulation models and should logically represent a combination of herd size, phase of production, and interaction with other pig holdings.

Materials and methods

Data collection

In order to generate data suitable for describing the extent of interactivity between pig holdings in New Zealand, information on location (easting and northing coordinates), demographics (herd size, production type, species residing on the premises), and farm contact network (movement distance and frequency of direct and indirect contacts with other farms) was required. Two existing databases were available to provide information about pig holding premises in the country. The New Zealand Pork Industry Board (NZ Pork), a statutory producer board, provided a list of all piggery owners (predominantly full-time pig farmers) who have voluntarily registered with NZ Pork. While registration with NZ Pork is voluntary, in excess of 90% of the supply of pigs to commercial abattoirs is provided by registered piggery owners. This list of premises was combined with data from AgriBase to create a single database for analysis. The combined database could then be interrogated to identify a list of all premises in New Zealand known to have held at least one pig sometime during the prior 18 months; this list of premises served as the sampling frame for the study. At the time of the study,

there existed no mandatory identification and tracking system for pigs in New Zealand and the situation remains the same today.

Development of farm-type categories for different types of pig holdings was to be completed through an objective analysis of data collected through a postal survey (described below) and a subjective review of that analysis by an industry consultation group composed of the investigators, disease control officials from the Ministry of Agriculture and Forestry (MAF), and pig industry representatives. Ultimately, the goal was to establish a minimum number of farm-types that could satisfactorily categorise all types of pig-holding premises that existed in the country.

Postal questionnaire

A questionnaire (included below as Supplementary information) was mailed out to the owners of all premises included in the study sampling frame (n=7,255) defined by the combined NZ Pork and AgriBase databases. As the sampling frame included all known pig holdings in New Zealand, the survey was considered to be a prospective census of the industry. The questionnaire was designed to identify the distance, frequency, and type of movements occurring onto and off pig holdings. The questionnaire was developed in conjunction with NZ Pork and was voluntarily tested on four piggeries and revised prior to distribution. In addition to the collection of standard demographic information about each pig holding premises and about the piggery owner's management style, questions were included to capture specific information related to: the movement frequency and distance for all major disease conveyors known to be associated with transmission of either of two representative exotic diseases (foot and mouth disease or classical swine fever) including pigs, semen, feed, effluent, people, trucks, and wildlife; the direction of each identified movement (away from the piggery, towards the piggery, between piggeries); and other miscellaneous characteristics thought to be informative for risk factor identification (waste food feeding, mortality disposal, presence of multiple livestock species on the premises). In the questionnaire, each piggery owner was requested to list all movements of these potential disease conveyors that occurred during the two-week period immediately prior to filling out the questionnaire. Piggery owners were also queried as to their personal motivation for being involved in the pig industry. It was thought that this information might be associated with particular behaviours that increased the biosecurity risks of that piggery and perhaps serve as useful criteria in establishing farm-type definitions. The data collection phase of the study occurred from February through April 2008. As an

incentive to participate in the study, each respondent was entered into a draw for a free three-day travel holiday for two people. A response rate of at least 20% was targeted for the study.

Statistical analysis

Data generated by this study was held and manipulated in Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) with further analyses of the data carried out as described below.

The correlation between herd size as defined by either total pigs or breeding herd size, and the piggery owner's level of commercial motivation (as compared to rearing pigs as a companion animal) was determined using Spearman rank order correlation calculated in R v2.14.1 (R Development Core Team, 2011; R Foundation for Statistical Computing, Vienna, Austria). This information was then used in order to determine if herd size could fairly represent a piggery owner's commercial motivation in formulating definitions for farm-types.

To evaluate whether non-respondent bias was present in the study, a subjective evaluation of the spatial representativeness of the respondents was undertaken by mapping each respondent's location then visually assessing the extent of spatial overlap between the sampling frame and the respondents. To determine if spatial clustering of respondents was significantly different compared to the underlying population that was surveyed, the data were explored by means of 999 Monte Carlo replications of an isotopic circular scanning tool in SaTScan™ v8.1.1 software (Martin Kulldorff, 2009; Harvard Medical School, Boston MA, USA) (Kulldorff 1997). Using Kruskal-Wallis rank sum test, non-respondents were also contrasted to respondents based on their predominant farming activity (pigs, sheep, dairy, forestry, etc.) as recorded in AgriBase.

Estimates of the frequency of movements of animals and semen are necessary for the operation of most disease outbreak simulation models. In this study, movement frequency data were analysed using two different methods. First, the frequency of movements per month based on median values from each farm was calculated using data from only those piggeries reporting at least one movement of that type. This provided an easily understood measure of the frequency of movements that occurred on piggeries. Second and more suitable for disease transmission modelling, the daily lambda parameter (number of movements per day) for the best-fitted Poisson distribution of each movement type was calculated using data from all piggeries, including those with no reported movements of that type. Data on the frequency of pig

and semen movements were analysed by these two methods in R using a maximum likelihood method to establish the best fitted Poisson distribution parameter for each type of movement (Venables and Ripley 2002). Movement frequencies were calculated without regard to the size (i.e. number of pigs involved) of a movement event.

Results

Representativeness of the New Zealand pig industry

In the postal survey, 7,255 questionnaires were mailed out and this represented an effort to conduct a complete census of all premises known to have recent history of pig ownership. A total of 275 of these premises had been identified through their listing on the NZ Pork register, which is in effect a list of premises which farm pigs as a business. Of these 275 premises, 127 questionnaires were returned yielding a 46.2% response rate; 89.8% of these respondents (114 piggeries) reported they had been involved in pig-related activities during the previous two-week period, suggesting they were still actively involved in the industry. Questionnaires were mailed to 6980 farms recorded in the national farms data base "AgriBase" as including pigs among animals on the farm when the file was last reviewed, but were not included in the NZ Pork register (suggesting that in general, pig farming was not a primary enterprise on these farms). Typically, such people are a mix of those who keep pigs continuously as a sideline or hobby, and opportunist pig keepers who buy a few young pigs to rear for meat when they are available, but may go for short or long periods with no pigs on the farm. Of these farms, 1,814 (26.0%) responded to the survey with 1363 of these (75.1%) reporting that they currently owned pigs at the time of the survey. All non-respondents and respondents reporting that they did not currently own pigs were purged from the dataset leaving 1,477 records (114 commercial and 1363 non-commercial piggeries) for further descriptive analysis. A map showing locations of premises involved in the Phase 1 survey is shown in Figure 12 on Page 153. An analysis that compared the spatial clustering pattern of the individuals who were sent questionnaires to the pattern of those people who responded to the survey found no significant differences, though there was evidence that a single 200 km radius cluster in Taranaki may have been slightly under-sampled (218 respondents versus 288 expected respondents; RR=0.71, p=0.08). This analysis provided good evidence that the survey respondents adequately represented the spatial distribution of New Zealand piggeries.

Respondents were also contrasted to non-respondents based on their predominant farming enterprise activity as recorded in AgriBase. Among those commercial piggeries

registered with NZ Pork, there was no difference in the proportion of respondent versus non-respondent farms classified across all of the 34 farming enterprises listed in AgriBase (Kruskal-Wallis rank sum test; p=0.31). Among those farms not registered with NZ Pork, there was an overall significant difference (Kruskal-Wallis rank sum test; p=0.02) in the proportion of farms involved in the different farming enterprise types. However, the most discrepant type described as 'sheep and beef farming', was only slightly less prevalent among respondents (17%) than non-respondents (21%). Therefore, given the large number of premises in the analysis, the discrepancies between respondents and non-respondents in enterprise types were minor.

Three factors were considered in establishing the target response rate for this study. The first and most critical factor was related to the need to know the typical size of herds of various herd types. Based on analysis of the existing data on pig farms in New Zealand (from AgriBase and NZ Pork), commercial herds were expected to have a mean size of around 170 breeding sows (and a standard deviation of 50) with non- and para-commercial herds expected to have a mean size of around 5 breeding sows (and standard deviation of 3). To have 95% confidence in estimating the true mean herd size in these two populations with a precision of +/- 10 commercial sows or +/- 2 non-commercial sows, a sample size of 97 or 9 herds respectively, was required. Having an accurate estimate of herd size was important as it would serve as key denominator for other metrics. The second factor considered was related to the fact that multiple types of questions were to be used in the study (journaling, open-ended, multi-choice, short answer) which made exact calculation of sample size requirements difficult from a quantitative perspective. Given prior knowledge about the size and management practices of both the commercial and non-commercial sectors of the industry by the sponsor and the research team, a subjective assessment of this factor was completed and a consensus was formed that the targeted response rate be set at 20%. The third factor that was considered in establishing an expectation of response was related to practical aspects of undertaking what was acknowledged in advance to be a challenging task - a limited project budget and short timelines for data collection, analysis, and reporting.

Defining farm-types

Creation of standard farm-types by which piggeries could be classified was required in order to complete a stratified analysis of the data obtained from the questionnaire. Additionally, it was important to establish farm-type criteria as the disease outbreak simulation software utilised in New Zealand for exotic disease response planning is

dependent on knowledge of the movement patterns between piggeries (Stern 2003). Through a process that incorporated use of the industry consultation group described above, a review of the survey data were undertaken and a classification system was proposed based on several criteria, namely: Pig inventory (breeding herd size and post-weaning herd size, evaluated independently), a piggery owner's self-ascribed motivation for raising pigs (i.e. to what extent, in the owner's opinion, was the raising of pigs a commercial enterprise), and characteristics related to a piggery owner's interaction with the different potential disease conveyors. The extent of 'commercial' motivation reported by a piggery owner was significantly correlated with both breeding herd size (Spearman rho=0.58, $p<0.001$) and total herd size (Spearman rho=0.58, $p<0.001$) which permitted the use of herd size as a simple and defensible proxy measure for the extent of a piggery owner's commercial motivation. Based on this finding, respondent piggeries were ranked by herd size then subjectively assessed by the industry consultation group to identify natural break-points for herd size that could be used in defining farm-types. Farm-type definitions were finally determined based on combination of herd size and the nature of pig movements occurring on a herd. Herds were classified based on conditional criteria that incorporated information both on the number of breeding sows and the total inventory of all pigs on the premises. If a premises had greater than or equal to 500 total pigs, or had at least 50 breeding sows it was classified as 'commercial'. Those premises having at least ten but fewer than 500 total pigs, and of which fewer than 50 were breeding sows were classified as 'para-commercial'. All premises having fewer than ten total pigs, regardless of type were classified as 'non-commercial'.

When these three categories were combined with the nature of pig movements that were identified through the survey, seven final farm-types were identified for further analysis: Commercial genetic supplier (a piggery supplying semen, boars, or gilts to other piggeries), commercial feeder (moves off the piggery limited to abattoir deliveries), commercial weaner producer (moves off the piggery including but not limited to weaned pigs), para-commercial genetic supplier (smaller commercial piggery supplying semen, boars, or gilts to other piggeries), para-commercial feeder (smaller commercial piggery with moves off the piggery limited to abattoir deliveries), para-commercial weaner producer (smaller commercial piggery with moves off the piggery including but not limited to weaned pigs), and non-commercial herds. Herds in the dataset that could not be categorised because they reported no pig inventory information were analysed

and reported separately. The distribution of piggeries in each farm-type category is shown in Table 12 on Page 146.

Pig movements on and off farm-types

The frequency of pig movements on and off the seven farm-types was analysed. Movements 'onto' piggeries were analysed separately from movements 'off' piggeries as the type of pig associated with these two movement directions was substantially different (e.g. replacement females only moved onto piggeries in most instances whereby slaughter weight pigs only moved off piggeries in most instances). Pig movement frequency data for most farm-types was highly skewed as many piggeries in the dataset had zero or very few pig movements. A summary of all pig-related movements onto and off of the study piggeries is presented in Table 13 on Page 147. These movements included gilts, boars, semen, weaned pigs, and all movements to an abattoir. The farm-type with the highest frequency of movements off the piggery was para-commercial genetic suppliers with a median of 5.3 movements off per month; commercial genetic suppliers reported 3.6 movements per month off the piggery. However, given the limited size of the New Zealand commercial pig industry, only a small number of piggeries are likely to operate as genetic suppliers and in this study, only one commercial and one para-commercial genetic supplier were willing to participate, thereby limiting the extent which strong inferences could be made about their activity. In fact, the commercial genetic supplier represented in the study was unwilling to provide any details about the size of their customer base and the frequency with which they interacted with individual clients. For this reason, we had no direct information on the movement of semen off commercial genetic suppliers though we did have information from commercial piggeries that were receiving deliveries of semen. Commercial feeders had the second highest off farm movement with a median of 4.6 movements per month. These moves primarily represented movements to an abattoir at a rate of approximately once per week, a typical pattern for many piggeries in commercial production. The highest frequencies of movements on to a piggery were experienced by commercial genetic suppliers (3.5 per month) and commercial feeder piggeries (2.6 per month) comprised of delivery of semen or replacement gilt/boars. In general, para-commercial and non-commercial farm-types reported less frequent movement activities both onto and off the piggery then their commercial counterparts. In order to assess the frequency of pig movements onto or off the various farm-types that was associated with saleyards and abattoirs, the data presented in Table 13 on Page

147 were stratified into either those movements that were directly between piggeries (Table 14, Page 148) or those movements limited only to saleyards and abattoirs (Table 15, Page 149). In the current study, 87 piggeries reported moving pigs to or from saleyards and 48 (55%) of these only undertook the activity two times or less per year. The survey did not collect information regarding the further movement of pigs once delivered to a saleyard. It was assumed that some pigs involved in this type of movement would return to other piggeries and some would be further transported to an abattoir. Given the overall small number of movements to saleyards and the unknown further destination of the pigs, the saleyard data were combined with abattoir data for further reporting purposes.

Commercial (3.3 per month) and para-commercial (6.5 per month) genetic suppliers reported high frequencies of movements off a piggery that were destined to arrive at another piggery. These movements again reflected the important contribution of replacement gilts and boars to the extent of contact between farm-types. Commercial feeder farm-types also reported high numbers of pig movements (4.1 movements per month). When we investigated this further, this reflected movements of pigs between distinct geographic sites but within coordinated multi-site production systems, not through trade of weaner pigs between piggeries of different owners (which was captured in the ‘weaner producer’ farm-type data). Commercial weaner producer farm-types reported 3.8 movements per month off farm which supported the notion that movement of weaner pigs between piggeries, whether between different owners or simply between sites in a single production system, contribute substantially to the contact rate between piggeries.

Pig movements to abattoirs were a very frequent activity reported in this study. The highest frequency of movements off farm, and across all farm-types was for commercial feeders at 8.4 movements per month. Logically, and supported by our review of the individual data points comprising this number, nearly all of these movements described abattoir deliveries. Commercial weaner producers reported the second highest movement frequency off farm at 2.9 movements per month, nearly all of which were related to movement of weaner pigs to a saleyard. Para-commercial feeder farm-types reported the highest frequency of movements onto farms at 1.4 movements per month and likely represented at least some of the reciprocal movements associated with commercial weaner producer delivery to saleyards. However, these two numbers disagree in magnitude suggesting an under-reporting of movements from saleyards by

some farm-types. As was the situation for all movements of pigs reported in Table 13 on Page 147 above, para-commercial and non-commercial farm-types in general reported less frequent movement activities both onto and off farm than their commercial counterparts.

To study further those movements between farm-types, exclusive of abattoir and saleyard-related deliveries, a subset of the data pertaining to movement of either replacement boars and gilts, semen, or weaner pigs was analysed (Table 16, Page 150). Semen delivery on to piggeries was the most important source of contact amongst these movement types for all commercial farm-types at 0.05 to 0.28 deliveries per day. Movement of replacement boars and gilts constituted another important source of contact between piggeries. Commercial and para-commercial genetic suppliers were understandably the most frequent source of these movements generating 0.11 and 0.17 movements per day, respectively. Movement of weaner pigs from commercial weaner producers (0.12 movements per day) and para-commercial genetic suppliers (0.11 movements per day) to other farm-types was the most frequent source of these movements in the study.

Relationship of movements between farm-types

While estimates of the discrete movement frequencies of pigs, onto or off different farm-types is useful for disease outbreak and biosecurity planning, the combined knowledge that comes from describing the frequency of movement types between farm-types is even more informative. Knowledge of the beginning and endpoints for every movement (rather than a tally of the total moves on, and the total moves off, a sample of piggeries) would be necessary to gain this information, and would allow direct measurement of the extent of contact between piggeries. Participants in this study were generally unwilling to provide detailed delivery information that described from what specific piggery a delivery arose, or to what other specific piggery a delivery was destined, though they were in most instances willing to provide an estimate of the distance involved in the movement. Based on the one-sided estimates of movement on frequency, movement off frequency, and knowledge of the New Zealand industry provided by members of the industry consultation group, the frequency of movements of pigs and semen between farm-types was estimated (Table 17, Page 151). The overall frequency of pig movements off each farm-type was greatest for commercial genetic suppliers at 0.2614 movements per day, a result of the fact this farm-type creates movements that can include semen, weaner pigs, replacement gilts, and replacement

boars. Other farm-types (excepting para-commercial genetic suppliers) were considered to only create movements of a single movement type resulting in a lower likelihood of their contact with another piggery. From this data, it was apparent that commercial farm-types interacted most frequently with other commercial farm-types. Similarly, less commercial farm-types interacted most frequently with other less commercial farm-types. The outliers amongst this general relational rule existed as a result of trade in weaner pigs. Twenty-one percent of the movements originating from commercial weaner producers were estimated to be for delivery onto para- or non-commercial farm-types. The inverse was not true as no movements originating from para- or non-commercial farm-types were identified as being for delivery onto commercial farm-types.

Analysis of movement distances

The frequency of movements of pigs and semen onto piggeries over different distances, and the distributions of those movement distances by farm-type are shown in Figure 13 on Page 154. The overall mean and median delivery distances for pigs and semen moving onto piggeries across all industry sectors was 64.3 and 30 km, respectively (SD 93.9; range 1–480 km). The distribution of delivery distances that occurred onto piggeries in the three industry sectors were similar with commercial piggeries having a median of 30 km, para-commercial of 43 km, and non-commercial of 25 km. Eighty-five percent of the total movements across the sectors had their origin less than 100 km away. The commercial piggeries did have a wider range of movement distances compared to para- or non-commercial piggeries; these were a result of a sparse number of movements (14%) occurring beyond 200 km.

The frequency of movements of pigs and semen off of piggeries over different distances and the distributions of those movement distances by farm-type are shown in Figure 14 on 155. The overall mean and median travel distances for pigs and semen moving off piggeries across all industry sectors was 122.4 and 50 km, respectively (SD 149.4; range 1–620 km). In contrast to the very similar distribution of movement distances on to piggeries in the three industry sectors, the distributions of movements off piggeries is very different among the three industry sectors. Pig and semen movements leaving commercial piggeries had a median of 98 km, para-commercial of 20 km, and non-commercial of 38 km. While the para- and non-commercial sectors were somewhat similar in median distance and distribution with less than 5% of movement occurring beyond 100 km, 52% of movements off commercial piggeries occurred beyond 100 km.

When investigated, the majority of these long distance commercial off-farm movements were associated with movement of market pigs to abattoirs and further explained the bimodal frequency distribution of off-farm movements shown in Figure 14 on Page 155. This situation is logical given that nearly 80% of commercial pig slaughter in New Zealand is limited to only four locations.[7]

Discussion

Pig breeding and raising in New Zealand, whilst a relatively small scale industry in comparison to dairy or sheep farming, is an important part of the agricultural production landscape of the country. Maintaining a viable domestic pork production base remains strategically important for the domestic economy and for food security. A key component of remaining a competitive producer of meat protein is retaining the uniquely good health status enjoyed by the New Zealand pig industry. A robust disease surveillance and response system is required to ensure that any pathogen introduction into the pig industry is rapidly identified before widespread transmission occurs. The current study established criteria for defining piggery farm-types based on data readily available in New Zealand national farm databases provided data on the extent of interaction between pig-holding premises that is suitable for use in disease outbreak simulation modelling. The study has also provided information to the pig industry about strategic locations (both geographical locations and contact-based network locations) that are likely to be important in biosecurity and surveillance planning exercises.

This study showed that New Zealand has a relatively small and widely dispersed commercial pig production industry along with a relatively large number of para-commercial and non-commercial premises distributed widely across the country. Premises in these three industry sectors have substantial geographic overlap so in the event of an exotic disease incursion, early detection and management of an effective response may be challenging.

While New Zealand enjoys the benefits of having several large national databases (including AgriBase utilised in this study) that capture many of the demographic details of farms operating as a commercial enterprise, the possibility remains that non-commercial properties with livestock still remain undiscovered as there is no national requirement that livestock be identified or reported. As of June 30, 2007 Statistics NZ reported a total of 327 farm holdings of at least one hectare that kept pigs; on these

[7] FL Clement, NZ Pork, Wellington, New Zealand.

holdings were a total of 39,743 breeding females (Anonymous 2007). The current study was able to identify 275 of these holdings, of which 127 responded to a mail-out questionnaire. Unfortunately, no such census of non-commercial piggeries occurs in New Zealand making an estimate of the total population size, both in terms of number of premises and total number of pigs, a challenging task. For this study, we were able to generate a list of 6,980 pig-holding premises from AgriBase that were not included in the NZ Pork voluntary register; of these 1,814 responded to the survey with 1,363 reporting they owned pigs at the time they filled out the questionnaire. AgriBase is primarily a database of information about commercial farms though some non-commercial farms or 'lifestyle blocks' are recorded through voluntary disclosure or as might be detected as part of a non-pig related regional disease surveillance programme.[8] In a study commissioned by MAF, an inventory of 139,868 lifestyle blocks were reported in the New Zealand Valuation Roll with a mean block size of 5.53 ha (median=2.7, range 0.0006–955.7 ha) (Sanson et al 2004). Of these, between 22,687 and 60,213 properties (depending on choice of 'lifestyle block' definition) were simultaneously captured in AgriBase. In that study, a sample of 3,934 of these properties was mailed a survey of which 947 (28%) usable responses were returned to the investigators. Only fifteen (1.58%) of the respondents reported pig ownership suggesting that perhaps only 2,209 lifestyle blocks across the country held pigs; this is in contrast to the current study whereby in excess of 6,000 properties in AgriBase had evidence of recent pig holding. An accurate count of properties in New Zealand holding pigs remains an elusive yet important piece of information for disease outbreak planning activities.

An important outcome of this study was the development of criteria suitable for categorising farm-types. Given the non-commercial industry is several times larger (in terms of number of premises) than the commercial industry and the diverse pig-related activities in which these farms are involved, it was desirable to generate farm-type definitions that did not simply rely on a metric that described the herd size without some evidence that the pig trading behaviour of the piggery owner was also related to herd size. The behaviours of the piggery owner as represented by their level of commercial motivation, and the piggery operational structure (type of pig or semen movements leaving the farm), were combined to create farm-types that reflected the nature of

[8] Personal communication. Robert Sanson, AsureQuality, Palmerston North, New Zealand.

interaction between farms and the risk related to the kind of pigs being moved off the farms. New Zealand does not yet operate a programme of mandatory pig identification and has only limited knowledge of the location of non-commercial pig holdings. Data provided through this study is sufficient to make informed use of disease transmission modelling software but is likely to be inadequate for identifying key players or physical locations in the para- or non-commercial sectors. A number of countries have instituted systems for pig traceability and livestock premises identification. While these systems are poised to be very useful in assisting with investigation of animal disease emergencies, their current design is imperfect. Non-compliance issues, complexity, and the cost of the systems appear to be important barriers to their implementation, especially in non-commercial segments of pig industries (Schwägele 2005; Hernández-Jover et al 2009). The importance of engagement with New Zealand's substantial non-commercial industry to any future iteration of premises identification or pig traceability schemes should not be underestimated.

Of note is the very sparse data from the survey that was available on genetic suppliers. By definition, this category included both semen and gilt/boar suppliers, each of which could be expected to have somewhat different characteristics from a disease risk profile point of view. Data were collected from only a single commercial piggery that acted primarily as a genetic supplier. This piggery supplied both semen and gilts so we believed the only appropriate way to manage its data was to categorise it simply as a ‘genetic supplier’ and recognise that limited inferences could be made from their data. This is in line with our general knowledge of the New Zealand industry as there are only two main companies in New Zealand that principally supply genetic stock to commercial producers. Both these companies provide both semen and breeding gilts to their clients.

The frequency of movement of pigs and semen on and off New Zealand piggeries has been described. Several key observations can be generalised from the data: On-farm and off-farm movement frequencies for each of the farm-types are different; movements to abattoirs constitute a substantial majority of off-farm movements; piggery owners were unwilling to provide sufficient level of detail about the exact origin and destination of pig movements to construct any form of trading network diagram; and pig movements in New Zealand are only rarely conducted through saleyards.

Reports of contact rates between piggeries are rare in the peer-reviewed literature. One report from the United States reported direct and indirect contact rates for backyard

(≤10 animals) and commercial piggeries (Bates et al 2001). For backyard piggeries, movements onto the piggery resulting in a direct contact event were estimated to occur 0.060 times per day and movements off the piggery that resulted in direct contact with another piggery were estimated to occur 0.056 times per day. For commercial piggeries (up to 2,000 pigs), direct contacts onto the piggery were estimated to occur 0.040 times per day and movements off the piggery were estimated at 0.159 times per day. These estimates are consistent with values reported in the current study for New Zealand commercial and para-commercial piggeries but are consistently higher than what was found for New Zealand non-commercial piggeries (Table 14, Page 148). Unique to the study were estimates of the frequency of contacts between different farm-types among the commercial, para-commercial, and non-commercial industry sectors. A limited number of studies have been published describing contact rates between piggeries in various countries. A Swedish study highlighted the need to utilise well-thought out farm-type definitions and found, similar to the current study, that only a few key farm-types are responsible for most of the inter-farm contacts that are likely to contribute to a multi-farm disease outbreak (Lindstrom et al 2010). In a study similar to the current one, the frequency of contacts between different type of piggeries in Belgium were described but with the benefit of access to a national database of animal movements information in addition to information gleaned from a postal survey (Ribbens et al 2008). In contrast to the New Zealand situation, Ribbens reported the most frequent movement of pigs was related to breeding farms moving pigs to feeding sites. This difference can be attributed to the substantially different underlying structure of the New Zealand pig industry which is predominantly comprised of single-site, farrow-to-finish piggeries. Control of endemic Salmonellae infection in French piggeries has been studied through analysis of farm-type and contact networks (Lurette et al 2011). The authors again emphasised the importance of farm-type in disease control planning but interestingly found movement restrictions between farms needed to be supplemented by within-herd control measures to substantially impact the prevalence of an endemic pathogen such as Salmonella spp.

Data were collected to describe the distances involved in the trade or sale of pigs and semen in New Zealand. Median movement distances of semen and pigs onto piggeries from all three industry sectors are clustered around 35 km with a generally similar distribution pattern across each sector, the exception to this was a number of movements onto commercial piggeries that originated more than 100 km away as a

result of deliveries of semen and replacement genetic stock (Figure 13, Page 154). While movement of live pigs can be an important means of transmitting a number of diseases between farms, semen is also well known as a risk factor for disease transmission. Notable examples of the role of pig semen in widespread disease transmission include porcine reproductive and respiratory syndrome virus in Denmark in 1996 (Botner et al 1997) and classical swine fever in the Netherlands in 1997 (Elber et al 1999). Para-commercial and non-commercial piggeries either acquire genetic stock and semen from local sources or choose not to use external providers for this material. Movement distances of pigs and semen off piggeries however, differs depending on the sector of the industry being analysed. Similar to movement distances on-farm, the median distances of movements originating from para- and non-commercial piggeries were centred around 30–35 km (Figure 14, Page 155). However, commercial piggeries tended to deliver pigs and semen a much further distance (median 98 km). The discrepancy is largely a function of market pig delivery to abattoirs, a somewhat unique situation to New Zealand as there are relatively few commercially sized abattoirs available for their use and subsequently creating long travel distances for many piggeries. New Zealand has no mandatory requirements for livestock trailer hygiene on domestic movement of pigs.

The distance associated with specific movement types is particularly relevant to disease and response planning exercises. Movement bans are an important tool used in the early and middle stages of exotic disease incursions. However, movement bans create practical and financial hardships on farms as they serve as significant constraint to business operation. By understanding the distances associated with movement of pigs and semen under normal circumstances, national disease outbreak managers will be better able to implement logical and minimally disruptive movement bans in the face of disease outbreaks.

Knowledge of the frequency of movements of pigs and semen among different pig farm-types is useful in disease response planning exercises for the New Zealand pig industry. Similarly, the distance over which these movements occur helps to provide a framework for assessing the likely connectivity between specific piggeries, abattoirs, and sale yards that participate in the pig industry. Whilst providing data useful for improving scenario modelling, the study also highlights the inherent knowledge gaps that occur in the absence of mandatory livestock identification and tracking schemes. However, in New Zealand's example of an industry with substantially more non-

commercial pig holdings than commercial pig-holdings, mandatory schemes may not have a level of compliance sufficient to add value beyond their cost. For these reasons, education on biosecurity and exotic disease presentation, public awareness campaigns, sufficient veterinary involvement in the non-commercial sector, and robust systems to ensure border security will remain critical in keeping the New Zealand pig industry at its current level of disease freedom.

Acknowledgements

Funding for this study was provided by MAF. Assistance with database development and data input was provided by Angus Davidson, Grant Jeffrey, and Rhona MacKenzie from Prime Consulting International Ltd and staff at AsureQuality. The assistance of NZ Pork and its members in pilot testing the questionnaire is gratefully acknowledged.

References

*__Anonymous.__ 2007 Agricultural Census tables. Pig numbers by age, sex and farm type. http://www.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/2007-agricultural-census-tables/livestock.aspx#pig (accessed April 14, 2012). Statistics NZ, Wellington, New Zealand, 2007

*__Anonymous.__ New Zealand Country Freedom and Commodity Pest Lists. (accessed April 12, 2012). MAF Biosecurity New Zealand, Wellington, New Zealand, 2012

Bates TW, Thurmond MC, Carpenter TE. Direct and indirect contact rates among beef, dairy, goat, sheep, and swine herds in three California counties, with reference to control of potential foot-and-mouth disease transmission. *American Journal of Veterinary Research* 62, 1121-9, 2001

Botner A, Strandbygaard B, Sorensen KJ, Have P, Madsen KG, Madsen ES, Alexandersen S. Appearance of acute PRRS-like symptoms in sow herds after vaccination with a modified live PRRS vaccine. *Veterinary Record* 141, 497-9, 1997

Dee S, Batista L, Deen J, Pijoan C. Evaluation of an air-filtration system for preventing aerosol transmission of Porcine reproductive and respiratory syndrome virus. *Canadian Journal of Veterinary Research* 69, 293-8, 2005

Elber AR, Stegeman A, Moser H, Ekker HM, Smak JA, Pluimers FH. The classical swine fever epidemic 1997-1998 in The Netherlands: descriptive epidemiology. *Preventive Veterinary Medicine* 42, 157-84, 1999

Hernández-Jover M, Schembri N, Toribio JA, Holyoake PK. Evaluation of the implementation of new traceability and food safety requirements in the pig industry in eastern Australia. *Australian Veterinary Journal* 87, 387-96, 2009

Kliebenstein JB, Lawrence JD. Contracting and vertical coordination in the United States pork industry. *American Journal of Agricultural Economics* 77, 1213, 1995

Kulldorff M. A spatial scan statistic. *Communications in Statistics - Theory and Methods* 26, 1481-96, 1997

Lindstrom T, Sisson SA, Lewerin SS, Wennergren U. Estimating animal movement contacts between holdings of different production types. *Preventive Veterinary Medicine* 95, 23-31, 2010

Lurette A, Belloc C, Keeling M. Contact structure and Salmonella control in the network of pig movements in France. *Preventive Veterinary Medicine* 102, 30-40, 2011

Otake S, Dee SA, Rossow KD. Transmission of porcine reproductive and respiratory syndrome virus by fomites (boots and coveralls). *Swine Health and Production* 10, 59-65, 2002

Ribbens S, Dewulf J, Koenen F, Mintiens K, de Kruif A, Maes D. Type and frequency of contacts between Belgian pig herds. *Preventive Veterinary Medicine* 88, 57-66, 2008

***Sanson R, Pearson A.** Agribase - a national spatial farm database. In: 8th Symposium of the International Society for Veterinary Epidemiology and Economics. Pp 12.6.1-.6.3. (Paris, France) 1997

***Sanson R, Cook A, Fairweather J.** A Study of Smallholdings and their Owners: Ministry of Agriculture and Forestry Information Paper 53. *Ministry of Agriculture and Forestry*, Ministry of Agriculture and Forestry Information Paper No: 53, Wellington, New Zealand, 2004

Schwägele F. Traceability from a European perspective. *Meat Science* 71, 164-73, 2005

***Stern M.** Interspread Plus. http://www.interspreadplus.com/Home.asp (accessed April 12, 2012). EpiCentre, Massey University, Palmerston North, 2003

***Venables WN, Ripley BD.** Univariate Statistics. In: *Modern applied statistics with S*. Pp 107-38. Springer, New York, 2002

Yaeger MJ, Prieve T, Collins JE, Christopher-Hennings J, Nelson E, Benfield DA. Evidence for the transmission of porcine reproductive and respiratory syndrome (PRRS) virus in boar semen. *Swine Health and Production* 1, 7-9, 1993

Tables

Table 12. Numbers and percentages of 1,477 New Zealand pig holdings classified into distinct farm-typ supplier, F=Feeder and WP=Weaner producer) and stratified by the survey respondent's motivation fo equal 100.

	Commercial			Para-commercial		
Motivation for raising pigs[a]	**GS**	**F**	**WP**	**GS**	**F**	**WI**
A sole source of income	1 (100%)	19 (32%)	2 (18%)	0 (0%)	1 (2%)	0 (0
Pigs are an important source of income	0 (0%)	37 (63%)	9 (81%)	0 (0%)	15 (35%)	5 (12
Pigs are a minor source of income	0 (0%)	1 (1%)	0 (0%)	0 (0%)	16 (38%)	22 (5
Profit from pig farming is of secondary concern	0 (0%)	0 (0%)	0 (0%)	1 (100%)	9 (21%)	12 (2
I raise pigs occasionally to supply pork for my family	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (2%)	2 (4
I raise pigs as pets	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0
No reason disclosed	0 (0%)	1 (1%)	0 (0%)	0 (0%)	0 (0%)	0 (0

[a] More detailed descriptions are included in the questionnaire (Supplementary Table 1)

Table 13. The frequency of all pig movements onto and off of 1,477 New Zealand pig-holding premises number of movements per month for only premises reporting at least one movement, or by the mean n among all farms in the study and stratified by farm-type (GS=Genetic supplier, F=Feeder and WP=We

	Movements on		
Farm-type	**Median[a]**	**lambda[b]**	**Medi**
Commercial GS	3.5000	0.0350	3.60
Commercial F	2.6307	0.0160	4.62
Commercial WP	1.3016	0.0083	2.85
Para-commercial GS	ND[c]	ND[c]	5.30
Para-commercial F	0.9033	0.0026	2.44
Para-commercial WP	0.4534	0.0067	1.03
Non-commercial	0.4508	0.0083	0.52
Other	1.5402	0.0022	0.94

[a] Per month, includes only respondents that reported at least one movement
[b] Lambda is the same as the mean of the Poisson distribution (mean moves per day), includes all respondent
[c] No data reported

Table 14. The frequency of between-premises pig movements among 1,477 New Zealand pig-holding pr represented by the median number of movements per month for only premises reporting at least one m (lambda) of movements among all farms in the study and stratified by farm-type (GS=Genetic supplier producer).

	Movements on		
Farm-type	**Median[a]**	**lambda[b]**	**Medi**
Commercial GS	3.5000	0.0875	3.30
Commercial F	2.6792	0.0372	4.07
Commercial WP	1.3016	0.0207	3.84
Para-commercial GS	ND[c]	ND[c]	6.45
Para-commercial F	0.8866	0.0056	0.42
Para-commercial WP	0.6003	0.0015	1.22
Non-commercial	0.4188	0.0009	0.58
Other	1.8323	0.0046	0.67

[a] Per month, includes only respondents that reported at least one movement
[b] Lambda is the same as the mean of the Poisson distribution (mean moves per day), includes all respondent
[c] No data reported

Table 15. The frequency of abattoir- and saleyard-related pig movements reported by owners of 1,477 premises. Movements are represented by the median number of movements per month for only premis movement, or by the mean number (lambda) of movements among all farms in the study and stratified supplier, F=Feeder and WP=Weaner producer).

	Movements on		
Farm-type	**Median[a]**	**lambda[b]**	**Medi**
Commercial GS	ND[c]	ND[c]	N
Commercial F	0.6000	0.0005	8.40
Commercial WP	ND[c]	ND[c]	2.85
Para-commercial GS	ND[c]	ND[c]	N
Para-commercial F	1.3548	0.0011	1.80
Para-commercial WP	0.1822	0.0001	0.85
Non-commercial	0.2871	0.0001	0.66
Other	0.5457	0.0006	1.56

[a] Per month, includes only respondents that reported at least one movement

[b] Lambda is the same as the mean of the Poisson distribution (mean moves per day), includes all respondent

[c] No data reported

Table 16. The frequency of between-farm movements of weaner pigs and genetic material among 1,477 premises. Movements are represented by the mean number (lambda[a]) of movements among all farms i farm-type (GS=Genetic supplier, F=Feeder and WP=Weaner producer).

	Boars and gilts		Semen	
Farm-type	**On**	**Off**	**On**	**Off**
Commercial GS	0.0350	0.1100	0.2800	0.0000
Commercial F	0.0229	0.0226	0.0740	0.0147
Commercial WP	0.0160	0.0063	0.0509	0.0000
Para-commercial GS	0.0000	0.1650	0.0000	0.0000
Para-commercial F	0.0048	0.0013	0.0003	0.0001
Para-commercial WP	0.0016	0.0004	0.0000	0.0000
Non-commercial	0.0003	0.0001	0.0002	0.0000
Other	0.0004	0.0003	0.0021	0.0000

[a] Lambda is the same as the mean of the Poisson distribution (mean moves per day), includes all respondent

Table 17. The frequency of pig movements amongst different farm-types in a survey of 1,477 New Zeal estimates of the frequencies are represented by the mean number (lambda) of movements per day and movements occurring between specific farm-types (GS=Genetic supplier, F=Feeder and WP=Weaner p percentages.

		Destination farm-type					
Source farm-type	**Daily frequency[a]**	**Commercial GS**	**Commercial F**	**Commercial WP**	**Para-commercial GS**	**Para-commercial F**	**Pa comm W**
Commercial GS	0.2614	13%	42%	42%	0%	2%	
Commercial F	0.0481	0%	47%	13%	0%	26%	
Commercial WP	0.1450	0%	80%	0%	0%	9%	
Para-commercial GS	0.1669	0%	0%	0%	0%	99%	
Para-commercial F	0.0043	0%	0%	0%	0%	23%	3
Para-commercial WP	0.0375	0%	0%	0%	0%	48%	
Non-commercial	0.0026	0%	0%	0%	0%	12%	
Other	0.0010	0%	0%	0%	0%	30%	

[a] Lambda is the same as the mean of the Poisson distribution (mean moves per day), includes all respondents

Figures

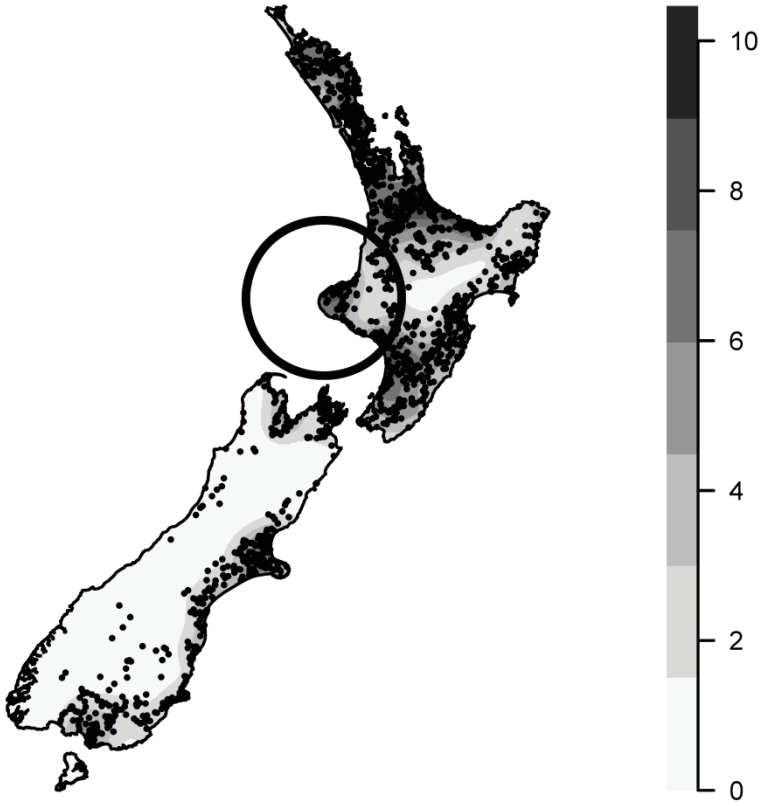
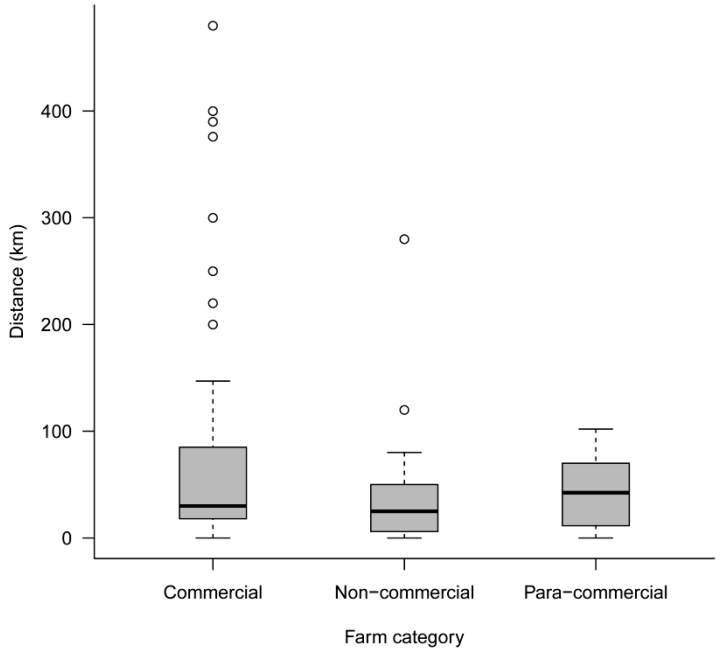


Figure 12. Density plot of all pig-holding premises contacted in Phase 1 survey (scale = number of pig-holding premises per 100 square-kilometres). Dots represent location of premises that responded to the survey. The circle identifies an area of the country where the number of respondent pig-holding managers was significantly less than expected based on the spatial density of holdings.

(a)



(b)

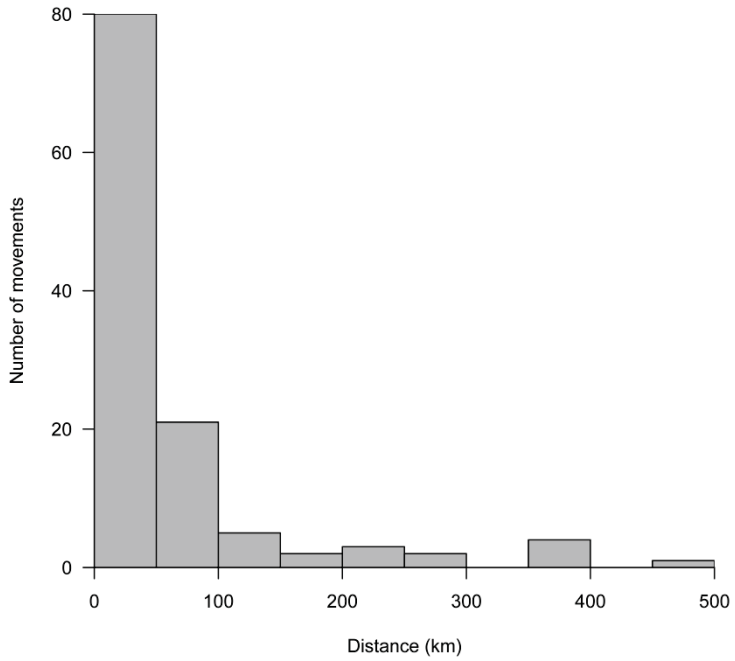
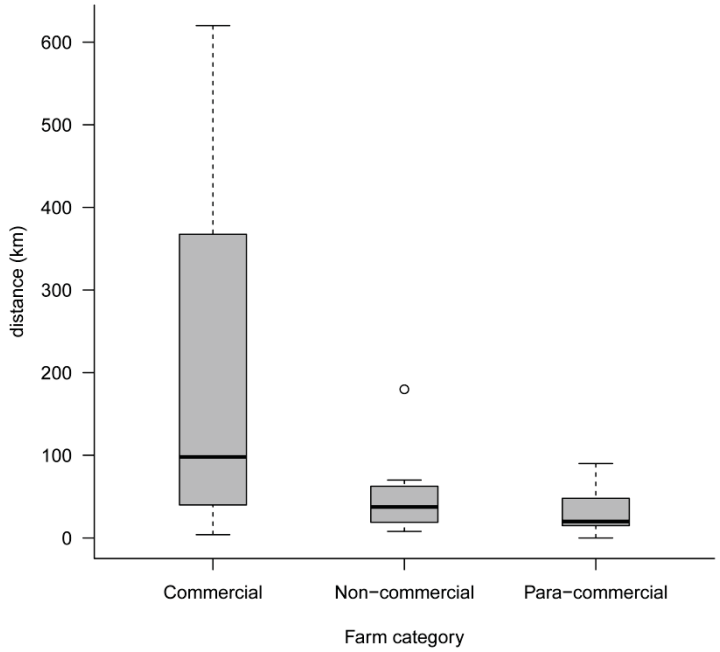


Figure 13. Figure (a) describes the median (dark line), interquartile range (upper and lower box limits), and the 5th and 95th percentiles (whiskers) of the movement distances of pigs and semen ON TO 1,477 New Zealand pig holding premises, stratified by farm-type; circles represent movement distances beyond the 95th percentile. Figure (b) describes the distribution of the same movements over various distances.

(a)



(b)

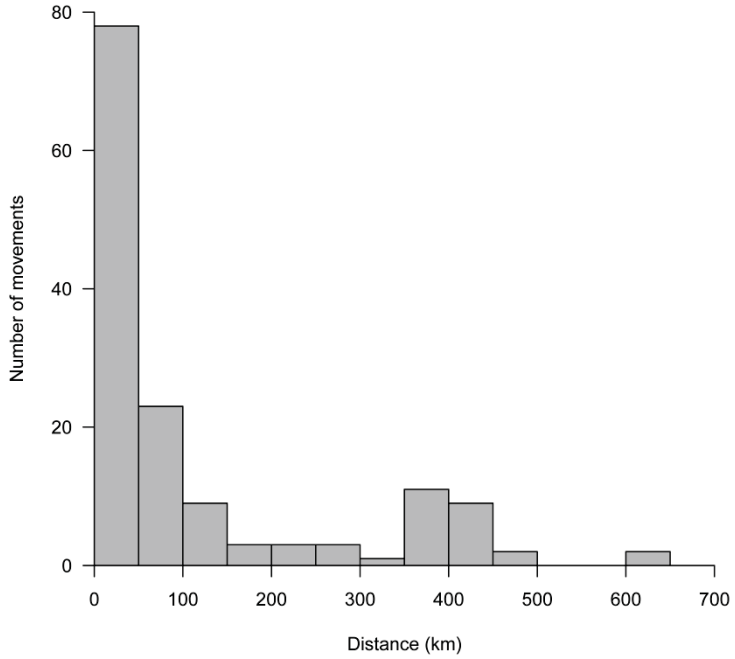


Figure 14. Figure (a) describes the median (dark line), interquartile range (upper and lower box limits), and the 5th and 95th percentiles (whiskers) of the movement distances of pigs and semen OFF 1,477 New Zealand pig holding premises, stratified by farm-type; circles represent movement distances beyond the 95th percentile. Figure (b) describes the distribution of the same movements over various distances.

Supplementary information

Postal Survey

1. *What is today's date?* Write in date here: _____

2. *How many animals are currently on your farm?*

LIVESTOCK CLASS		NUMBER
PIGS	- Breeding sows (including gilts selected for replacements)	
	- Weaner/ Grower/ Finisher pigs	
	- Breeding Boars	
	- Pig Other (e.g. pets)	
SHEEP	- Breeding ewes	
	- Replacements	
	- Dry stock – for meat or wool	
	- Other (including breeding rams)	
BEEF CATTLE	- Breeding cows	
	- Replacements	
	- Dry stock - for meat production	
	- Beef Other (e.g. breeding bulls, suckling calves, draught oxen)	
DAIRY CATTLE	- Milking cows	
	- Replacements	
	- Other (including breeding bulls)	
DEER	- Breeding hinds	
	- Stags for velvet	
	- Deer for meat	
	- Other (e.g. breeding stags, trophy animals)	
GOATS	- Total number	
HORSES	- Total number	
POULTRY	- Layers	
	- Replacements / pullets	
	- Broilers	
	- Others (including Turkeys and game birds)	
	- Ducks	

3. *What is the best description of your pig farming enterprise?* Please tick one category that describes the main reason you have pigs:

Predominant Type of Enterprise	Tick (✓)
Farrow-to-Finish	
Weaner Producer	
Finishing only	
Sale of breeding stock	

AsureQuality is collecting the information contained in this AgriBase™ update form in order that it may collate, deal with and use the information in such manner as AsureQuality reasonably thinks fit, and includes to:

- Enhance New Zealand's agricultural productivity and ability to trade.
- Help respond to and manage rural emergencies, diseases, pests, environmental quality issues and product quality issues.
- Help produce agricultural statistics.
- Assist fundraising by rescue services.

AsureQuality will hold the information securely against unauthorised access for use in accordance with the Privacy Act 1993. If you understand and are agreeable to the above, please sign and date the authorisation in the space allocated below.

I hereby authorise AsureQuality to use the information provided on this AgriBase™ update form in furtherance of any of the above purposes, whether with third parties or otherwise. I understand that I have the right of access to, and correction of, the information provided to AsureQuality on this form.

Signature: _____ Date: _____

4. *Which statement below best describes the importance of pig production to your lifestyle?* Please tick one category only.

Statement	Tick (✓)
I'm a commercial pig producer. Raising pigs is my only source of income.	
I'm a commercial producer, but raising pigs is not my only source of income.	
I raise pigs with the intent of them being profitable however they are a relatively unimportant source of income. I may go in and out of pigs depending on markets, availability of feed or other lifestyle choices from time to time.	
Pig farming is something I enjoy and making money from the pigs is not really important to me.	
I raise or fatten pigs occasionally, mainly for meat for the family	
Owning a pig is mainly for the pleasure of having a pet	

5. *How do you house your pigs?* Please fill in the table below, listing numbers of pigs on your property today for which each category of housing best applies. Please note the totals in the various 'housing type' categories should match with the total number of pigs of each type on your farm.

Class of pig	Number of Pigs in Housing Type		
	Indoors	Outdoors	Deep Litter
Breeding sows, boars and gilts			
Weaner pigs			
Grower / Finisher pigs			

6. *During the last calendar year FROM 1 JANUARY 2007 TO 31 DECEMBER 2007, of all the pigs sold or removed from your property, approximately what number and percentage of pigs were weaners/ stores, for slaughter, or for breeding?* Please write in the numbers and percentages in the table below. Remember to include all pigs, including all choppers.

Class of pig	Number Sold/ Moved	Percentage of Total Pigs Sold/ Moved
Weaners / Stores		%
Finisher Pigs sold to slaughter		%
Breeding gilts or boars		%
Choppers		%
Total Pigs Sold/ Moved		100%

NB. We also ask for percentages to be calculated, as a cross-check to ensure all pigs sold or moved are accounted for.

7. *For each of the items listed in the table below, please indicate the FREQUENCY with which items typically m*
normal year. Where the answer is nil for any item, please write in 'nil'. A 'movement' is a consignment e.g. a group o
question, we are not concerned with the number of items in a movement, only the frequency of movements.

Item	Number of Movements ON	Per Time Period (circle one)	N Mov
1. Pigs and pig genetic material			
Breeding sows / gilts (direct farm-to-farm)		Day / Wk / Mnth / Yr	
Breeding sows / gilts (via saleyard)		Day / Wk / Mnth / Yr	
Breeding boars (direct farm-to-farm)		Day / Wk / Mnth / Yr	
Breeding boars (via saleyard)		Day / Wk / Mnth / Yr	
Boar semen		Day / Wk / Mnth / Yr	
Weaner pigs (direct farm-to-farm)		Day / Wk / Mnth / Yr	
Weaner pigs (via saleyard)		Day / Wk / Mnth / Yr	
Pigs sent to abattoir for slaughter		Day / Wk / Mnth / Yr	
Other (describe): ……		Day / Wk / Mnth / Yr	
2. Other livestock			
Cattle		Day / Wk / Mnth / Yr	
Sheep		Day / Wk / Mnth / Yr	
Deer		Day / Wk / Mnth / Yr	
Goats		Day / Wk / Mnth / Yr	
Other (describe): ……..		Day / Wk / Mnth / Yr	

3. Animal feed			
Formulated pig feeds		Day / Wk / Mnth / Yr	
Delivery of traditional pig feed ingredients (e.g. bulk grains, protein sources)		Day / Wk / Mnth / Yr	
Commercial food waste or by-products for pig feeding (waste milk, restaurant waste, etc)		Day / Wk / Mnth / Yr	
Other livestock feed (describe): ……..		Day / Wk / Mnth / Yr	
4. Effluent / Manure			
Manure Trucks		Day / Wk / Mnth / Yr	
Other eg Compost etc		Day / Wk / Mnth / Yr	
5. People who may be in contact with pigs			
Farm staff travelling to / from other farms (incl their home)		Day / Wk / Mnth / Yr	
Farm staff visiting saleyards		Day / Wk / Mnth / Yr	
Farm staff visiting meat processing sites including abattoirs		Day / Wk / Mnth / Yr	
Farm staff visiting showgrounds / other animal sites		Day / Wk / Mnth / Yr	
Veterinarians		Day / Wk / Mnth / Yr	
Other pig consultants		Day / Wk / Mnth / Yr	
Livestock agents		Day / Wk / Mnth / Yr	
Other (describe): ……..		Day / Wk / Mnth / Yr	
6. Food meant for consumption by family or staff			
If you home-butcher pigs on your premises, how often does this occur?		Day / Wk / Mnth / Yr	
If you feed home “kitchen waste” to your pigs, how often does this occur?		Day / Wk / Mnth / Yr	

7. Dead animal disposal and method (burial, compost, rendering, etc)			
Pigs (list method): ……....		Day / Wk / Mnth / Yr	
Other livestock (list species and method): ……....		Day / Wk / Mnth / Yr	
8. Other vehicles or farm equipment not accounted for above loaned to/ borrowed from other farms eg. Tractor, front-end loader etc. (Please describe)			
		Day / Wk / Mnth / Yr	
		Day / Wk / Mnth / Yr	

8. *Specific Movements during the last TWO WEEKS:*

PLEASE READ THESE NOTES BEFORE CONTINUING:

1. The aim of this question, both parts 8.1 and 8.2 below, is to record as accurately as possible all movements
   off the property during the PREVIOUS TWO WEEKS. Don't worry if these weeks are not typical ones for your pro
   regarding what movements have occurred in the last two weeks.

2. Please note that "movements" includes a wide range of sources of potential disease spread, such as animals, anima
   vehicles, equipment and people. Animal products include milk, meat, wool and hides.

3. Many of these movements will have already been listed in Question 7 above, however for these questions we are int
   those movements that occurred in the last two weeks.

4. Please describe each item sufficiently well such that we can understand the magnitude of disease risk. We have give
   illustrate the level of detail required.

5. Please provide enough detail on the address such that we can calculate an accurate distance to or from your farm.

6. If necessary, photocopy extra pages to give yourself enough room to record all the movements.

8.1 Please list all MOVEMENTS coming ON TO your farm during the last TWO WEEKS (each day may require sev

REMEMBER, we're interested in all movements (including animals, animal products, feed, effluent / manure, vehic

Date	What or who moved ON TO your farm and details of each movement (how many, description, any other information you think might be useful)	Where FROM (physical address locality/suburb)
e.g. 26/02/08	20 gilts delivered from Farm A using their own truck	Farm A, 4035 Any Road, Pig Town
e.g. 07/03/08	9 tonnes complete feed delivered, XYZ Feeds Ltd truck	XYZ Feed Mill, 100 Main Road, Pi

8.1 MOVEMENTS ON contd.

Date	What or who moved ON TO your farm and details of each movement (how many, description, any other information you think might be useful)	Where FROM (physical address locality/suburb)

8.1 MOVEMENTS ON contd.

Date	What or who moved ON TO your farm and details of each movement (how many, description, any other information you think might be useful)	Where FROM (physical address locality/suburb)

8.2 Please list all MOVEMENTS LEAVING your farm during the last TWO WEEKS (each day may require several l

REMEMBER, we're interested in all movements (including animals, animal products, feed, effluent / manure, vehic

Date	What or who moved OFF your farm and details of each movement (how many, description, any other information you think might be useful)	Where TO (physical address or r locality/suburb)
e.g. 27/02/08	One of our farm trucks with 100 weaner pigs, of which 80 were dropped off at Farm A and 20 at Farm B	Farm A, 121 Any Road, Pig Town Farm B, 2450 Another Road, Pig T
e.g. 27/02/08	Sent our herdsman to neighbour's farm to help with their weaning day.	Farm C, 60 Number One Line, Pig

8.2 MOVEMENTS OFF contd.

Date	What or who moved OFF your farm and details of each movement (how many, description, any other information you think might be useful)	Where TO (physical address or r locality/suburb)

8.2 MOVEMENTS OFF contd.

Date	What or who moved OFF your farm and details of each movement (how many, description, any other information you think might be useful)	Where TO (physical address or r locality/suburb)

9. Are there any other comments you would like to make about this survey or the topic in general?

Thank you for your participation.

Please return your completed survey in the enclosed pre-paid envelope by 15 MARCH 2008 in order to be included in a draw for the free Air New Zealand mystery weekend trip.

Chapter 5. Effect of blood sample handling post-collection on *Erysipelothrix rhusiopathiae* antibody titres

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Abstract

AIMS: A study was conducted to determine the effect of blood sample mishandling on the performance of an enzyme-linked immunosorbent assay for the detection of antibodies against *Erysipelothrix rhusiopathiae*.

METHODS: Eleven sample maltreatments (storage at -10°C, storage at 4°C, heat treatment of clotted blood, haemolysis, repetitive freeze–thaw cycling, and substitution of plasma in place of serum) were simulated in a laboratory environment and then run concurrently against a gold standard sample (storage at -80°C).

RESULTS: The mishandling treatment groups that simulated high levels of haemolysis had significantly lower optical density (OD) readings when compared to the gold standard. However, the magnitude of the effects was relatively small and only samples with OD values close to the cut-off changed state from positive to negative. Heat treatment had a minor, but non-significant, effect on OD values.

CONCLUSIONS: Findings from this study suggested that immunoglobulin G antibody was stable in the face of most common sample mishandling events. While individual samples having antibody concentrations close to a test's positive cut-off may change status, the interpretation of serologic tests at a group or herd level are very unlikely to change.

CLINICAL RELEVANCE: If reasonable care is taken in the collection, transport, and laboratory handling of porcine blood samples, serological assays for detection of IgG antibodies can be expected perform reliability even when minor quality issues with the samples are known to exist.

KEYWORDS: Enzyme-linked immunosorbent assay, Blood, Serum, Agreement, Storage

Abbreviations

CCC	Correlation concordance coefficient
CI	Confidence interval
ELISA	Enzyme-linked immunosorbent assay
IgG	Immunoglobulin G
MANOVA	Multivariate analysis of variance
NFDM	Non-fat dry milk
OD	Optical density
PBS	Phosphate buffered saline
SDS	Sodium dodecyl sulphate

Introduction

Diagnostic laboratories and test kit manufacturers remind their customers that faultless blood sample handling (immediate chilling, no haemolysis, prompt serum-clot separation, and ultra-low temperature [-80°C] serum storage) is required prior to performing antibody-based assays in order to achieve reliable and accurate results (Lippi et al 2006). However, between the time of sample collection and subsequent disease antibody quantification, perfect handling rarely occurs given the daily vagaries of clinical veterinary practice. Whereas conventional wisdom and common sense dictate that mishandling of blood samples will adversely affect the outcome of diagnostic tests, studies assessing the effect of poor sample handling on enzyme-linked immunosorbent assay (ELISA) based serum antibody tests are lacking.

Using a repeated measures design, we investigated the effects of 11 different treatments designed to reproduce common veterinary practice sample handling deficiencies on anti-*Erysipelothrix rhusiopathiae* antibody quantification. *Erysipelothrix rhusiopathiae* is a bacterial pathogen of swine that causes an acute systemic infection commonly referred to as ‘diamond-skin disease’ or swine erysipelas. From previous work with swine erysipelas, the investigators had experience with an ELISA that was developed for detecting antibodies against *E. rhusiopathiae*, making it a convenient platform for conducting this current study (Neumann et al 2009).

Materials and methods

Blood sample collection

Blood samples were collected from 35 market-weight pigs by free-catch during exsanguination at a commercial slaughter facility. Each pig was first rendered unconscious by electrocution, then shackled by a rear leg and elevated. Within 30 s of electrocution, major arteries and veins in the thoracic inlet were severed, allowing exsanguination to occur.

During exsanguination, seven 8.5 mL blood collection tubes (BD Vacutainer SSTII Advance serum separator tubes, Becton Dickinson) were simultaneously filled by suspending them in the exposed blood stream. Each tube was capped promptly after collection. In addition, a 20 mL disposable plastic syringe was filled in the same manner and then used to fill, by vacuum, two 4 mL whole blood collection tubes (BD Vacutainer K2E 7.2 mg EDTA, Becton Dickinson) which were thoroughly mixed by inverting three times. At the end of the 30 min collection period, all tubes (n = 315) were placed in racks over ice for 2 h during transport to the laboratory.

Sample treatments

Eleven treatments were devised to simulate common types of sample mishandling practices that were thought likely to affect antibody quantification when compared to an optimal or 'gold standard' (GS) handling technique (Table 18, Page 184). Upon arrival at the laboratory, five of the serum separator tubes and one EDTA tube (per pig) were immediately centrifuged at 1260 x *g* for 12 min; serum or plasma was then decanted into 1.8 mL snap-cap plastic conical tubes. The two remaining serum separator tubes (per pig) were placed into a 50°C water bath prior to centrifugation for either two or six hours, at which time they were centrifuged and serum harvested. The single remaining EDTA tube from each pig was immediately frozen at -10°C in order to disrupt the red blood cells and create a haemolysate for subsequent use in the study.

By collecting an adequate number of blood samples from each of 35 pigs, all mishandling treatments could be applied to samples from each pig. This repeated measures design allowed each pig to serve as its own control and minimized the between-pig variation that would otherwise reduce the statistical power of the study. The statistical power for this study was calculated to be 0.98 with 95% confidence based on an effect size of 0.27, 12 groups, and 35 samples per treatment. The power analysis was completed using R: A Language and Environment for Statistical Computing (R Development Core Team (2009). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria) and the pwr package (Stephane Champely (2009). pwr: Basic functions for power analysis. R package version 1.1.1).

In order to provide reference ELISA values to which all other treatments could be compared, gold standard (treatment GS) samples were first created by processing and centrifugation, as described previously, then immediately freezing at −80°C. Eleven sample mishandling treatments were then constructed.

As many veterinary clinics do not have access to ultra-low freezer storage, the first two treatments were devised to simulate blood sample storage conditions more typical in practice. The effect of extended storage of serum at refrigerator temperature was simulated by placing an aliquot of serum from each pig into storage at 4°C (treatment C4) and the effect of serum storage in a common chest-type freezer was simulated by storage of a second aliquot at −10°C (treatment C10); both aliquots were stored for 14 days.

To simulate the effect of a sample being held in summer (perhaps inside an enclosed practice vehicle), a third and fourth treatment were devised. Two clotted but non-separated whole blood sample from each pig were immersed in a 50°C water bath for either 2 or 6 h (treatments HEAT502 and HEAT506, respectively). After heating, samples were centrifuged and sera was decanted, then stored at −80°C.

To determine the effect of haemolysis on ELISA values, we used five more treatments. Paired samples of serum and freeze–thawed whole blood in EDTA were combined to create a set of 5%, 10%, 25%, 50%, and 100% (v/v) mixtures for each pig (treatments H5, H10, H25, H50 and H50, respectively). These mixtures were created just prior to ELISA testing from aliquots of GS serum and the EDTA samples that were frozen shortly after collection.

A tenth mishandling treatment was constructed to mimic the occasion when a veterinary practitioner inadvertently collects a blood sample in the wrong 'type' of collection tube (an EDTA tube instead of a serum tube, for example) and is tempted to use the sample for antibody quantification regardless. To simulate this, a whole blood sample from each pig was collected in EDTA, centrifuged at 1260 x *g* for 12 min, and 1.8 mL of plasma was decanted; plasma was then stored at −80°C until analysed (treatment P).

Finally, to determine the effect of repetitive freezing and thawing on detectable serum antibodies, an eleventh treatment was planned (treatment FT). In a practice setting, veterinarians routinely archive serum samples, collect paired serum samples for paired testing (e.g. acute and convalescent disease), or have freezer malfunctions that result in a freeze–thaw event; all of these have the potential to affect the quality of an antibody-based test. To create a 'worst-case' scenario that might represent these situations, an aliquot of serum from each pig was placed into a 1.8 mL snap-cap conical tube, which was then subjected to 14 daily freeze–thaw cycles (22 h at −10°C, followed by 2 h at room temperature).

When not prevented by the specific mishandling treatment protocol that was applied, all samples were stored for 14 days at −80°C prior to performing the ELISA.

ELISA

Whole blood and sera that had been previously frozen were removed from their respective storage environments on Day 14 and thawed at 4 °C; ELISA assays were then completed the following day. Haemolysis mixtures were created just prior to ELISA analysis on Day 15. To create the haemolysis mixtures, four 0.5 mL aliquots of GS sera were prepared for each pig. Next, the whole blood samples in EDTA that had

been frozen on Day 1 were thawed, then centrifuged for 12 min at 1260 x *g* and either 26, 56, 167, or 500 µL volumes were collected from the sample supernatant and mixed into each of the 0.5 mL aliquots of serum (5%, 10%, 25%, and 50% v/v mixtures, respectively). A further 0.5 mL of the centrifuged whole blood supernatant was placed into a separate 1.8 mL tube to represent the 100% v/v haemolysis sample.

Prior to ELISA testing, all samples (35 GS samples plus [11 treatments × 35 pigs] = 420 samples) were diluted 1:160 in a 0.01 M phosphate buffered saline (PBS) diluent containing 0.3% Tween 20 and 1.15% non-fat dry milk (NFDM). The ELISA was carried out as follows: each well in the plates (96-well MaxiSorp F98 plates, Nunc) received 100 µL of coating buffer (0.159% Na2CO3 plus 0.293% NaHCO3, in Super Q Water, pH 9.6) plus antigen (1.4 µg inactivated whole-cell preparation of *E. rhusiopathiae*, per well) and was incubated overnight at 4°C.

On the day of the assay, plates were removed from 4°C storage and manually washed six times with a 0.01 M PBS wash reagent containing 0.3% Tween 20. Following washing, each well was blocked with 200 µL of 1.15% NFDM in 0.01 M PBS containing 0.1% non-ionic detergent (Igepal CA-630, Sigma–Aldrich) and 0.01% antifoaming agent (Antifoam Y-30 Emulsion, Sigma–Aldrich), then incubated for 60 min at 37 °C. After incubation, the plates were washed six times with wash reagent, then 100 µL of the diluted serum sample were applied to each cell; 100 µL of positive control serum (1:2560, serum:diluent) and negative control serum (1:80 serum:diluent) were applied in duplicate to each plate. Plates were incubated at 37°C for 30 min, samples were removed, and plates washed six times with wash reagent.

Following washing, 100 µL of horseradish peroxidase-conjugated goat anti-swine immunoglobulin G (IgG 0.5 mg/mL, heavy and light chains, Kirkegaard and Perry Laboratories) at a 1:2000 dilution were added to each well. The plates were incubated for 30 min at 37°C and washed six times, then developed by adding 100 µL of 2,2′-azino-di-(3-ethylbenzothiazoline-6-sulfonic acid) substrate (ABTS 0.3 g/L, Kirkegaard and Perry Laboratories) to each cell. After incubating for 30 min at 37 °C, the reaction was stopped by adding 100 µL of 1% sodium dodecyl sulfate (SDS). Optical density (OD) was measured immediately at dual wavelengths of 405 and 490 nm (OD 405/490); OD 405/490 of ≥0.200 was considered positive. In setting up the ELISA plates, the GS and all 11 mishandling treatments for a given pig were represented, in duplicate, on a single plate.

Statistical approach

Three analyses were completed to determine the existence and extent of any effect produced by the 11 treatments when compared to GS. Initially, a multivariate analysis of variance (MANOVA) with repeated measures was conducted to determine the existence of any difference across the treatments. A MANOVA approach was used because the assumption for sphericity (as assessed by Mauchly's Criterion) that is required for a univariate analysis of variance (ANOVA) with repeated measures approach was not met (Barcikowski and Robey 1984). A second analysis was conducted in order to simultaneously assess agreement in OD values among the 11 different sample treatments. A single correlation concordance coefficient (CCC) was calculated using a modification of Lin's original approach (Lin 1989). An overall CCC was calculated that included 95% confidence intervals (CI) generated through use of a bootstrapping technique (2000 re-sampling events) (Barnhart et al 2002). To determine the magnitude of each treatment effect on the change in OD value, a third analysis using a mixed-effects regression model was completed (PROC GENMOD; SAS version 9.1, SAS Institute). The net difference between GS and treatment OD was calculated for each sample (variable = DIFF) and was used as the dependent variable in the model. Each of the 11 treatment variables was dummy coded and then included in the initial model as fixed-effect variables; a variable representing pig identification was included as a repeated effect. This initial model was run and all variables with a significance of $P > 0.25$ were removed from the model. The final regression model included only terms that represented treatments H50, H100, and HEAT502.

Results

The MANOVA test for differences among treatments using Wilks' Lambda criteria was significant ($F[11, 24] = 9.83$; $P < 0.0001$). Follow-up orthogonal contrasts between the GS and each of the other treatments were conducted to identify specific treatments that influenced the sample OD values. The H100 treatment group had significantly lower OD values than the GS group ($F[1, 34] = 13.98$, $P < 0.0007$). No other treatment groups were found to be significantly different from GS. A plot of sample medians for the GS and each treatment is shown in Figure 15 on Page 187.

Among all 12 treatment groups, the overall CCC was determined to be 0.9301 (95% CI = 0.8439 − 0.9882), suggesting a very high level of agreement amongst the treatment groups; a value of 1.0 would have indicated perfect concordance. Based on results of the MANOVA analysis that suggested that the H100 treatment had a significant effect on

OD values, a further CCC calculation was made to determine the concordance specifically between GS and H100. While the resulting CCC of 0.8749 (CI = 0.7742 − 0.9324) indicated less concordance than was determined by the overall CCC calculation, the level of agreement between the GS and H100 treatments was still very high. A plot of H100 versus GS OD values is presented in Figure 16 on Page 187.

The mixed-effects regression modelling confirmed the significance of several treatments that were previously identified in the MANOVA and CCC analyses. After removing non-significant terms, the final regression model included only terms that represented treatments H50, H100, and HEAT502; the individual pig term remained in the final model as a repeated effect. The final model is shown below:

(Equation 1)

DIFF = -0.0089 – (0.0419 * H50) - (0.1365 * H100) – (0.0390 * HEAT502)

Type III Wald Chi-square statistics were calculated for each variable in the final model using the SAS generalised estimating equation function (H50: $\chi 2 = 8.33$, $P = 0.0039$; H100: $\chi 2 = 52.00$, $P < 0.0001$; HEAT502: $\chi 2 = 7.24$, $P = 0.0071$) and corroborated previous findings that heat treatment and excessive levels of haemolysis are likely to have an effect on ELISA OD values.

Discussion

Diagnostic serological testing is an important and useful tool for identifying the presence of swine pathogens and understanding their epidemiological features. Veterinary practitioners are frequently reminded of the importance of good pre-analysis sample handling if accurate and reliable results are expected. Unfortunately, guidelines as to what exactly constitutes poor sample handling or poor sample quality are only described in very broad terms (Niederman 1973; Catty and Raykundalia 1988; Turgeon 2003). This study was designed to examine the effect of 11 maltreatments on antibody concentration in haematological samples.

Three separate statistical analyses of the data were completed and each identified the H100 treatment (extreme haemolysis) as causing a significantly lower OD value compared to the GS. The CCC between GS and H100 was determined to be 0.8749 (1.0 representing perfect concordance), indicating that concordance was not perfect but that a reasonable amount of agreement still existed. The regression modelling reinforced the statistical significance of the H100 treatment on OD values but also suggested that H50

and HEAT502 may have had important effects on the level of quantifiable antibody. The parameter estimates associated with all three-treatment variables (β estimates of −0.0419, −0.1365 and −0.0390 for H50, H100, and HEAT502, respectively) were very small, indicating a statistically significant, but not biologically significant effect.

From the standpoint of the clinician, the magnitude of an ELISA OD reading may have only limited value beyond simply indicating that antibody is present in the sample. Instead, the more practical implication is the likelihood or frequency that sample maltreatment resulted in the sample changing status (i.e. from positive to negative, or vice versa). In light of the minimal impact on ELISA OD values among any of the treatments, no effort was made to analyse the impact of sample treatment on change of status.

An analysis of residuals from the linear regression modelling suggested the treatment effect of H50, H100, and HEAT502 was linear throughout the range of OD values in the dataset. This supports our assertion that the likelihood of a sample changing status would be most influenced by its nearness to the positive cut-off value. The proportion of samples that changed from a positive to negative state after maltreatment is shown in Table 19 on Page 185. While nearly 40% of samples changed state in the H100 treatment group, the overall interpretation of any of the 11 maltreatment groups, at least at a herd or population level, would not have changed and the population could still be identified as having been exposed to *E. rhusiopathiae*.

The utility of this particular ELISA test at an individual animal level has not been evaluated. The particular maltreatments evaluated in this experiment had a moderate effect in lowering OD values and appeared unlikely to simply change true positive samples into negative samples. Therefore, only those samples with OD levels close to the positive cut-off level were likely to change state.

Our study did not investigate the mechanism for the lower mean OD values reported in H50, H100, or HEAT502 treatments. While both H50 and H100 samples were both slightly viscous and opaque, the 1:160 dilution step prior to running the ELISA probably minimised the colorimetric effect on the resulting OD values. Molecular level interactions between immunoglobulins and haemoglobin may have reduced the binding affinity for the ELISA antigen, or perhaps the lower OD values were simply a result of physical interactions occurring between the haemoglobin, cellular debris, and ELISA reagents.

The very modest effect that resulted from heat treatment was surprising. Previous reports have indicated that heat denaturation of antibodies can be prevented by storing serum at 4°C or less (Niederman 1973), implying storage temperatures >4°C have a detrimental effect on detectable antibody levels. Enzymes and other physiologically active proteins function maximally at normal biological temperatures (37–39°C) and their functionality (due to disruption of tertiary protein structure) would be expected to decline as storage temperatures rise. Therefore, we expected that exposing serum samples to a relatively high temperature for extended periods of time would disrupt the antibody proteins. While heat treatment for 2 h did have a statistically significant effect on the amount of detectable antibody, the magnitude of the effect was biologically irrelevant.

Also surprising was the lack of influence on detectable antibody levels produced by repeatedly freezing and thawing serum samples. Similar to effects caused by heating, repeated freezing and thawing was anticipated to compromise tertiary bond structure in antibody proteins. A possible explanation for the apparent lack of effect in both the heated and freeze–thawed treatment groups may be related to the specific antibody isotype being detected by the ELISA used in this study.

Compared to IgM and IgA, IgG has a relatively simple structure that may be less prone to damage due to temperature changes. IgG comprised only a single immunoglobulin (in the normal heavy and light chain configuration) and is not bound to other immunoglobulins (as in the case of the pentameric polypeptide structure of IgM or linear structure of IgA). The specific antibody isotype detected by the ELISA used in this study can be assumed to be IgG given that the secondary antibody in the ELISA was anti-IgG and should have had no or negligible reactivity to either IgA or IgM.

Conclusions

This study has challenged many of the conventionally held beliefs about sample handling and its effect on serological antibody quantification. Serum antibodies appear to be substantially more robust than previously thought and OD values are stable even in the face of severe sample mishandling. Additionally, at least within the context of this *E. rhusiopathiae* ELISA, plasma appeared to be an acceptable substitute for serum. The effect of the sample mishandling treatments applied in this study on antibodies against other disease agents is unknown.

Acknowledgments

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References

Barcikowski RS, Robey RR. Decisions in Single Group Repeated Measures Analysis: Statistical Tests and Three Computer Packages. *The American Statistician* 38, 148-50, 1984

Barnhart HX, Haber M, Song J. Overall concordance correlation coefficient for evaluating agreement among multiple observers. *Biometrics* 58, 1020-7, 2002

***Catty D, Raykundalia C.** Production and Quality Control of Polyclonal Antibodies. In: Catty D (ed) *Antibodies - A Practical Approach*. Pp 19-80. IRL Press, Eynsham, Oxford, England, 1988

Lin LI. A concordance correlation coefficient to evaluate reproducibility. *Biometrics* 45, 255-68, 1989

Lippi G, Guidi GC, Mattiuzzi C, Plebani M. Prenalytical variability: the dark side of the moon in laboratory testing. *Clinical Chemistry and Laboratory Medicine* 44, 358-65, 2006

Neumann EJ, Grinberg A, Bonistalli K, Mack HJ, Lehrbach PR, Gibson N. Safety of a live attenuated Erysipelothrix rhusiopathiae vaccine for swine. *Veterinary Microbiology* 135, 297-303, 2009

***Niederman JC.** Methods Used in Conducting Serum Surveys. In: Paul JR, White C (eds). *Serological Epidemiology*. Pp 33-41. Academic Press, Inc, New York, New York, USA, 1973

***Turgeon ML.** Safety and Basic Techniques in the Immunology-Serology Laboratory. In: *Immunology and Serology in Laboratory Medicine*. Pp 115-29. Mosby, St. Louis, Missouri, USA, 2003

Tables

Table 18. Description of common blood sample mishandling practices and the post-collection treatmen reproduction in a laboratory setting.

Treatment	Mishandling simulation	Sample treatment post-collection
GS	Gold standard control	Sera in ultra-low storage (-80°C) for 14 days
C4	Separated serum left in refrigerator for 14 days	Sera in refrigerator storage (+4°C) for 14 days
C10	Separated serum stored in a conventional chest-type freezer	Sera in conventional storage (-10°C) for 14 days
HEAT502	Clotted blood left in vehicle for 2 h during warm weather	Clotted whole blood samples immersed in water bath (separation and ultra-low storage (-80°C) for 14 days
HEAT506	Clotted blood left in vehicle for 6 h during warm weather	Clotted whole blood samples immersed in water bath (separation and ultra-low storage (-80°C) for 14 days
H5	Minimal haemolysis	5% dilution (v/v) of haemolysed whole blood in sera
H10	Modest haemolysis	10% dilution (v/v) of haemolysed whole blood in sera
H25	Significant haemolysis	25% dilution (v/v) of haemolysed whole blood in sera
H50	Severe haemolysis	50% dilution (v/v) of haemolysed whole blood in sera
H100	Extreme haemolysis	100% haemolysed whole blood
P	Inadvertent collection of blood in EDTA rather than serum tubes	Two-hour chilling on ice, plasma separation, ultra-low
FT	Repeated freezing and thawing for multiple assays	Two hours chilling on ice, serum separation, -10°C sto temperature and re-freezing daily for 14 days

Table 19. Effect of sample mishandling on ‘positive’ or ‘negative’ test interpretation post-treatment.

	GS	C10	C4	H5	H10	H25	H50	H100
Number positive samples	35	31	35	35	35	35	33	22
Number negative samples	0	4	0	0	0	0	2	13
Percent changing state	0	11.4	0	0	0	0	5.7	37.1

Figures

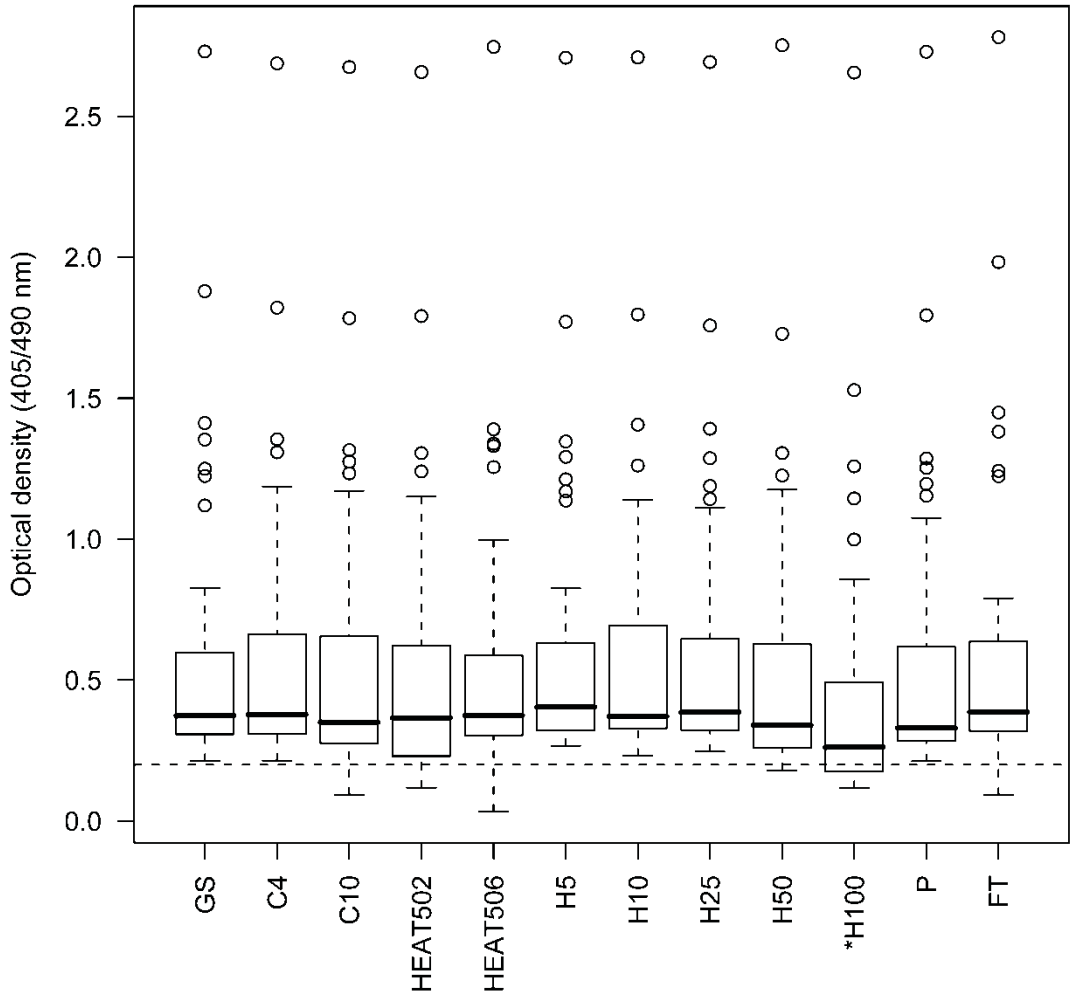

Figure 15. Box-and-whisker plot of sample treatment effects on anti-*E. rhusiopathiae* antibodies. Optical density (OD) values at or above the dotted line (0.200) are considered positive. The centre line in the boxes represents median values, the box encloses the interquartile range and the whiskers extend to the most extreme data point, which is no more than 1.5 times the interquartile range from the box. GS = gold standard, C4 = 4°C, C10 = 10°C, HEAT502 = 50°C for 2 h, HEAT506 = 50°C for 6 h, H5 = 5% haemolysis (v/v), H10 = 10% haemolysis (v/v), H25 = 25% haemolysis (v/v), H50 = 50% haemolysis (v/v), H100 = 100% haemolysis (v/v), P = plasma, FT = repetitive freeze–thaw. *Significantly lower than GS ($P < 0.0007$).

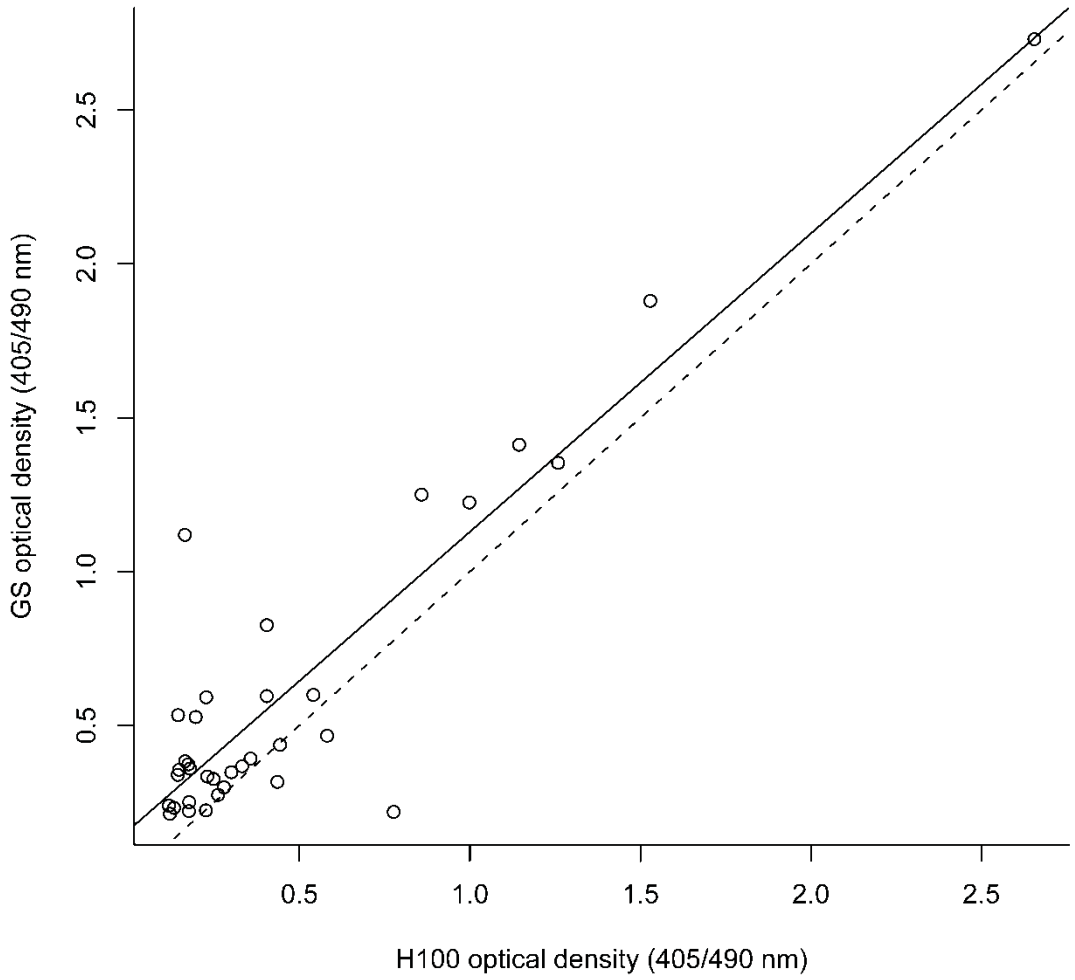

Figure 16. Concordance correlation coefficient plot of GS and H100 treatment (CCC = 0.8749, a value of 1.0 would indicate perfect concordance). Solid line plotted using least squares regression (adjusted r^2 = 0.8226, y = 0.15993 + 0.96941 × H100, P < 0.0001); dashed line represents equality or perfect concordance. GS = gold standard, H100 = 100% haemolysis (v/v).

Chapter 6. Descriptive and temporal analysis of post-mortem lesions recorded in New Zealand slaughter pigs from 2000-2010

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Abstract

AIMS: The objective of this study was to complete a retrospective analysis of data from a national abattoir-based lesion recording system (PigCheck) in the New Zealand pig industry. The study established the prevalence of 20 post-mortem disease lesions, described long term trends in the prevalence of these lesions, and identified the proportion of the monthly variation in lesion prevalence that could be attributed to individual farms and abattoirs.

METHODS: Data on lesion prevalence from 2000 through 2010 was aggregated by month and time-series analysis of the data for each lesion was conducted. The time series pattern for each lesion was described with an auto-regressive integrated moving average (ARIMA) model; seasonality of lesion occurrence was assessed separately. To determine the proportion of variance in lesion prevalence that could be attributed to farms relative to that attributed to abattoirs, a hierarchical binomial generalised linear mixed model was created incorporating two random effect levels, at the farm (within abattoir) and abattoir levels.

RESULTS: A dataset comprised of 124,407 lots (6,220,664 pigs, 279 farms, five abattoirs) was compiled for analysis. Three lesions formed a cluster of the most prevalent conditions across the 11 year time series: antero-ventral pneumonia (7.57%), pleuropneumonia (11.43%), and milk spots (9.21%). Ten of the 15 lesions shown to have a significant trend were decreasing over time and five were increasing. The lesions for which the abattoir, relative to the farm explained a significantly greater proportion of variance in prevalence included pyogenic lesion (92%), mange (73%), and ileitis (62%). The three lesions for which the farm explained the greatest proportion of variance in prevalence included rectal prolapse (98%), pneumonia (97%), and antero-ventral pneumonia (96%).

CONCLUSIONS: The overall prevalence of most lesions recorded in PigCheck for the period was low relative to published data from other countries. Common lung pathologies contributing to lesions such as pneumonia and pleurisy were primarily a function of farm management and were not likely due to variability in lesion recording at different abattoirs.

CLINICAL RELEVANCE: Based on the low frequency of lesions in pigs at commercial abattoirs, the health status of pigs in New Zealand pig industry is considered to be very good. Pneumonia, pleurisy, and ascariasis are some of the most

prevalent conditions which should be focussed on through development of herd health management plans.

KEY WORDS: Pig, Epidemiology, Population Surveillance, Abattoirs, Pneumonia

Abbreviations

ACF	Autocorrelation function
ARIMA	Auto-regressive integrated moving average
MAF	Ministry of Agriculture and Forestry
NZ Pork	New Zealand Pork Industry Board
NZD	New Zealand dollars

Introduction

Programmes have been established in many countries around the world to collect data at abattoirs that describe the presence of lesions or disease agents in pig carcasses that are associated either with poor meat quality or that present a risk to human health. Less frequent are standardized and on-going programmes to collect information from abattoirs that can inform producers about the presence or frequency of diseases that are important because of their negative impact on cost of production rather than their relationship to foodborne diseases of people. Such national programmes are known to exist in some countries including Great Britain (Sanchez-Vazquez et al 2011), Netherlands (Blocks et al 1994), Scandinavian countries (Olsson et al 2001), United Kingdom (Sanchez-Vazquez et al 2011) and New Zealand (Anonymous 1999) with additional informal, producer-driven efforts likely occurring in most other countries that have modern pig industries. However, these informal "slaughter-checks" tend to be periodic rather than on-going, are targeted at specific known problems rather than comprehensively survey a broad range of disease conditions, are customized to a specific farm's or veterinarian's needs rather than approached systematically, and whose results are not routinely published.

NZ Pork, a statutory board established by the Pork Industry Board Act (1997) to represent the interest of pig farmers, developed a formal national programme to survey for the presence of important production limiting diseases in market weight pigs delivered to commercial abattoirs. The programme called PigCheck[9], was developed in 1997 in collaboration with farmers, veterinarians, and a third-party auditing firm[10] who also had responsibility for food safety inspection in these same abattoirs. PigCheck was initially modelled after a similar programme developed in Australia (Pointon et al 1987) called the Pig Health Monitoring Scheme which was later modified for use in the United States under the name of PigMON (Pointon et al 1992; Davies et al 1996). PigCheck records the occurrence of 20 pre-defined carcass and viscera lesions (Table 20, Page 209) in real-time on every pig slaughtered in the five largest pig abattoirs in New Zealand. PigCheck data are recorded on approximately 94% of commercial pigs in

[9] PigCheck™, http://www.asurequality.com/services-to-the-meat-processing-industry-mandatory-and-contestable/online-services.cfm.

[10] AsureQuality, AsureQuality House, Level 4, 8 Pacific Rise, Mt Wellington, Auckland, New Zealand; http://www.asurequality.com/.

the country and is funded directly by producers at a rate of approximately $0.17 NZD per pig slaughtered[11].

PigCheck data are available to individual farmers and their veterinarian within one to two days of collection through pre-formatted online reports. Farmers are only able to view data from their own farm, though some summary analysis across multiple farms is likely carried out by veterinarians for sharing with their clients. No formal national reporting from the PigCheck system has previously been carried out resulting in a limited perspective on the overall health status of commercial slaughter pigs in New Zealand.

The objective of this project was to complete a retrospective analysis of the existing PigCheck data with the specific aims of establishing the prevalence of post-mortem disease lesions, describing any long term trends in the prevalence of these lesions, and identifying the proportion of the monthly variation in lesion prevalence that can be attributed to individual farms and abattoirs.

Materials and methods

With permission of NZ Pork, a complete download of all PigCheck data collected between January 2000 and December 2010 was obtained. The data for this study were held and manipulated in Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) with further analyses carried out as described below. Slaughter lesion data were collected and reported at the lot level; no individual pig level data were available. The data were examined and criteria were developed to ensure only reliable data were retained for further analysis: Lots of more than 1000 head were removed as these were believed to represent either data entry errors, or multi-day data aggregations with loss of farm-level detail; lots with zero animals were removed as they represented data entry errors; and lots were removed when the proportion of affected pigs (for any recorded lesion) was calculated to be greater than 100% as they were assumed to represent data entry errors. Lesion data were reported in a dichotomous manner with the lesion being recorded as either present or absent in each carcass.

Statistical analysis

All statistical analyses were completed in R v2.14.1 (R Development Core Team (2011). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria). Descriptive analysis of data was completed

[11] Personal communication; Patrick Turton, AsureQuality, Ashburton, New Zealand.

using the epiR package (Mark Stevenson with contributions from Telmo Nunes, Javier Sanchez, Ron Thornton, Jeno Reiczigel, Jim Robison-Cox and Paola Sebastiani (2012). epiR: An R package for the analysis of epidemiological data. R package version 0.9-43). Time series analysis was completed using the xts package (Jeffrey A. Ryan and Josh M. Ulrich (2012). xts: eXtensible Time Series. R package version 0.8-6) and forecast package (Rob J Hyndman with contributions from Slava Razbash and Drew Schmidt (2012). forecast: Forecasting functions for time series and linear models. R package version 3.25). Proportional variance analysis was conducted using the lme4 package (Douglas Bates, Martin Maechler and Ben Bolker (2012). lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-0) and boot package (Angelo Canty and Brian Ripley (2012). boot: Bootstrap R (S-Plus) Functions. R package version 1.3-7).

Time-series analysis of data for each lesion was conducted after aggregating lesion prevalence for each month of the study. The prevalence of each lesion was regressed on month to determine if a trend was present over the time period. When the slope of the fitted regression line was significantly different than zero ($P < 0.05$), the increasing or decreasing trend was considered to be significant. When a significant trend was identified, the time series was detrended then the time series pattern for the prevalence of each lesion was described by applying an auto-regressive integrated moving average (ARIMA) model to the detrended data. The ARIMA models were fitted using an automated procedure, then 95% confidence intervals for the coefficients of each model term calculated. When the 95% confidence interval for coefficient of any term contained zero, it was dropped from the model and the ARIMA model fitting procedure was completed manually. The overall fit of each time series model was assessed using Akaike Information Criteria (Diggle 1990); model residuals were examined by plotting them as a time series, assessing the autocorrelation function (ACF), and applying the Ljung–Box test for independence (Ljung and Box 1978). To evaluate the presence of any seasonal pattern in the prevalence of each lesion, a frequency analysis of the aggregated monthly data was conducted and the results were reported in the form of a periodogram. Each periodogram was subjectively inspected to identify the occurrence of peaks suggestive of a seasonal pattern.

The prevalence of pigs reported with each lesion was expected to vary between farms and between abattoirs. Over the period of data collection, different farms delivered pigs to different abattoirs creating a nested relationship in the data. To determine the

percentage of variance in lesion prevalence that could be attributed to farms relative to that attributed to abattoirs, a hierarchical binomial generalised linear mixed model was created. Lot was weighted by number of pigs in each lot. Two random effect levels were incorporated at the farm (within abattoir) and abattoir levels. Using a general linear model with a binomial linking function, the prevalence of each lesion in a lot was regressed on farm (name) within abattoir (name) and weighted by the number of pigs in the lot:

For lot *i*, in farm *j* in abattoir *k*, $\text{logit}(p_{ijk}) = \alpha + u_{jk} + v_k$ where u_{jk} and v_k were farm and abattoir level random effects, respectively.

Results

Summary information

The initial dataset extracted from PigCheck contained 155,724 records with each record representing an individual lot of pigs delivered to an abattoir for processing. These 155,724 records were comprised of lesion data reported from 7,090,179 pigs. After the dataset was cleaned as described above, the final dataset created for analysis contained 124,407 records (79.9% of data retained) and described the presence or absence of lesions on 6,220,664 pigs (87.7% of data retained). Data for the analysis were collected from January 2000 through December 2010.

Two-hundred and seventy-nine unique farms were represented in the dataset. Farms that only supplied pigs intermittently for slaughter or that supplied pigs in very small numbers (one or two pigs, with the pork typically being returned to the owner for personal consumption) were often not assigned a unique farm identifier in the PigCheck system. These farms were assigned a generic identification number and for the current analysis, their data was treated as if the pigs originated from a single farm (and which represented the 280th "unique" farm in the dataset).

Across the five abattoirs represented in the dataset, lesion information was collected from a mean of 47,126 (95% CI = 46,051 to 48,202) pigs each month. Eighty-three percent of the PigCheck data was derived from only three of the five abattoirs (abattoir A, C, and D). The mean lot size recorded was 50.0 pigs (95% CI = 49.7 to 50.3) with statistically significant differences in mean lot sizes noted between some abattoirs (Table 21, Page 210); however the mean lot sizes between abattoirs only ranged from 46.5 to 52.3 pigs suggesting that in practical terms lot size was very similar between abattoirs. Lesions were recorded from a mean of 942 (95% CI = 920 to 965) lots of pigs each month of the study. Approximately 94% of the annual pig slaughter in New

Zealand was conducted at the five abattoirs represented in this study;[11] no exact percentage could be determined as local and travelling butchers were active across certain regions of New Zealand and contributed an unknown number of pigs to the total annual slaughter number.

Time series analysis

Of the data recorded on the occurrence of the 20 PigCheck lesions, the occurrence of emaciation, full gut, and pericarditis lesions were sparse or intermittent so they were not evaluated as part of the time series analysis. Three lesions formed a cluster of the most prevalent conditions recorded across the 11 year time series (Table 22, Page 211): Antero-ventral pneumonia (mean 17.57%, CI = 17.45% to 17.7%), pleuropneumonia (mean 11.43%, CI = 11.33% to 11.53%), and milk spots (mean 9.21%, 95% CI = 9.09% to 9.32%). A second cluster of four common lesions was identified though at a much lower prevalence: Rectal prolapse (mean 5.77%, 95% CI = 5.7% to 5.84%), mange (mean 3.63%, 95% CI=3.58% to 3.68%), pleurisy (mean 3.13%, 95% CI = 3.1% to 3.16%) and septicaemia (mean 2.69%, 95% CI = 2.65% to 2.73%). All other lesions were reported at less than 2% prevalence.

A significant trend (annual change in prevalence) was identified for every condition except pyogenic lesion, tuberculosis-like lesion, other lesion, and kidney condition (Table 22, Page 211). However, given the overall low prevalence of lesions it followed that the actual values for these annual trends were very small. The lesions with the most substantial annual decrease in prevalence were milk spots (decreasing 0.54 percentage points per year), pleuropneumonia (decreasing 0.97 percentage points per year), and antero-ventral pneumonia (decreasing 0.73 percentage points per year). By contrast, pleurisy (increasing 0.29 percentage points per year) and mange (increasing 0.23 percentage points per year) were identified as the lesions with the most substantial increases in prevalence. Of the 15 lesions with significant annual trends in prevalence, ten were decreasing and five were increasing.

The occurrence of each lesion was evaluated to determine the existence of any seasonal patterns. After detrending the data, conducting a frequency analysis, and evaluating the periodogram, no seasonality was identified in fifteen of the lesions. However, pleurisy and milk spot were found to each have a distinct seasonal pattern (Figure 17, Page 214). The prevalence of milk spot tended to peak during late-winter (July and August) particularly during the first two-thirds of the time series. However, as the overall prevalence of milk spot trended down during the period of study, the seasonal pattern

became less apparent. The prevalence of pleurisy peaked during early-summer (November and December) though the pattern was difficult to detect visually on the time series plot due to the overall low prevalence of the lesion.

The prevalence of positive farms for each of the 17 lesions that underwent a time series analysis was summarized in Table 23 on Page 212. Across the 11 years for which data were collected, more than half of farms were identified as having at least one positive pig for every condition except for ileitis, pyogenic lesion, and tuberculosis-like lesion. The most prevalent condition between-farms was milk spot (mean 91.8%, 95% CI = 87.9% to 94.7%).

Variance components

By examining the variance associated with farm and abattoir terms in the mixed model, the relative contribution of each to the observed differences in the overall prevalence of each lesion was determined. A summary of the findings is presented in Figure 18 on Page 215. Only data from the 279 farms with known unique identities was used in the analysis; lots attributed to a "generic" farm identification number (as described above) were excluded from the analysis.

The lesions for which the abattoir, relative to the farm explained a significantly greater proportion of variance ($p < 0.05$) in prevalence included pyogenic lesion (92%, 95% CI = 100 to 79%), mange (73%, 95% CI = 77 to 69%), and ileitis (62%, 95% CI = 78 to 46%). The lesions for which the farm explained a significantly greater proportion of variance ($p < 0.05$) in prevalence included rectal prolapse (98%, 95% CI = 70 to 100%), pneumonia (97%, 95% CI = 87 to 100%), antero-ventral pneumonia (96%, 95% CI = 87 to 100%), arthritis (96%, 95% CI = 79 to 100%), pleuropneumonia (94%, 95% CI = 88 to 100%), and septicaemia (92%, 95% CI = 81 to 100%). A significant amount of the variance in prevalence of broken back, bruising, pleurisy, milk spot and wound lesions was also explained by farm (versus abattoir) but the effect was less than noted for the lesions described above. When 95% confidence intervals for farm-attributed versus abattoir-attributed variance overlapped, the effect was considered to be unbiased or not significant, and this situation was identified for tuberculosis-like lesion, kidney condition, and other lesions.

Discussion

The New Zealand pig industry is free from many of the significant viral and bacterial diseases such as transmissible gastroenteritis, Aujeszky's disease, swine brucellosis, porcine reproductive and respiratory syndrome, and classical swine fever common to

much of the world (Neumann et al 2012). Unfortunately, the industry's small size relative to the substantial farmed ruminant industries in New Zealand means that much of the disease surveillance activities that occur in the industry must be funded by pig farmers. For this reason, pig farmers are interested not only in ensuring their investment in PigCheck surveillance provides useful information on behalf of the entire industry (supporting national efforts in biosecurity, trade, and exotic disease preparedness) but that it also provides information that is directly useful to the farmer in managing his own herd.

The 279 unique farms analysed in this study represented virtually all of the commercial pig production in the country from 2000 to 2010 and can therefore be considered to establish accurate benchmarks for the important production limiting diseases in New Zealand.

Antero-ventral pneumonia (17.57%) and pleuropneumonia (11.43%) featured significantly in the PigCheck data set. While less prevalent than other lung pathology, pleurisy lesions (3.13%) were also routinely identified in New Zealand pigs. Aside from their contribution to increased costs of production, lung pathology (particularly pleuropneumonia and pleurisy), creates problems in abattoirs because many of these carcasses require extra trimming and labour during processing.

Both infectious (virulent organisms) and non-infectious factors (housing, management, herd characteristics) contribute to development of pneumonia and pleuritis (Pointon et al 1985; Stark 2000). Slaughterhouse data from143 herds studied in France in 2006 to 2008 identified pneumonia occurring in 69% of the pigs and pleuritis was reported in 14.4% of the pigs (Fablet et al 2012). In this French study, the occurrence of pneumonia was associated with having less than four weeks downtime between batches, larger group sizes, and high concentrations of CO_2. Risk factors for pleuritis were somewhat different (having farrowing facilities attached to finishing facilities, castrating male pigs later than 14 days of age, and larger group size) from those identified for pneumonia. A 2007 study in Belgium determined the prevalence of pneumonia (20.76%) and pleuritis (23.85%) in slaughter pigs (Meyns et al 2011). This Belgian study showed that seropositivity to *Mycoplasma hyopneumoniae* or *Actinobacillus pleuropneumoniae*, and increased numbers of nursery pigs per pen were positively associated with pleuritis; the presence of pleuritis and frequent purchases of pigs were positively associated with the occurrence of pneumonia. Pleuritis and cranio-ventral pulmonary consolidation were found in 26.8% and 55.7% of slaughter aged pigs in a study of pigs in Spain in 2007

(Fraile et al 2010). In this Spanish study pneumonia lesions were related to the type of finishing barn ventilation, and *M. hyopneumoniae* or swine influenza seropositivity. Pleuritis was most significantly related to lack of all-in all-out pig flow management, and seropositivity to *A. pleuropneumoniae* or porcine reproductive and respiratory syndrome virus. Data from the United Kingdom from 2005 to 2008 showed that 80% of consignments and 12.5% of pigs had pleurisy (Jager et al 2012). In an abattoir based study of lesions in Netherlands from 1987 to 1989, the highest prevalence of pneumonia (11-12%) was reported in mid-winter and lowest in mid-summer (Elbers et al 1992). In contrast, the highest prevalence of pleurisy (6-8%) was in mid-summer and lowest in mid-winter. In the current study of New Zealand slaughter pigs, the highest prevalence of pleurisy occurred in the spring. Though the existence of a seasonal effect was unequivocal, the magnitude of the effect only amounted to approximately a 1% increase in prevalence during the peak months. Given New Zealand's generally mild climate relative to the climatic conditions impacting the Netherland study, it is reasonable to expect a less dramatic seasonal effect in New Zealand.

Few studies of abattoir lesions in pigs raised in the southern hemisphere have been published in recent years. In 1995 (winter) and 1996 (summer), a longitudinal study of pig farms in New Zealand was undertaken to identify risk factors for respiratory disease. Winter time prevalence of enzootic pneumonia (cranio-ventral pneumonia typically associated with *M. hyopneumoniae* infection) was 63.4%, pleuropneumonia 2.7%, and pleurisy 19.1%; enzootic pneumonia was significantly lower (52.2%) in the summer than in the winter. In this New Zealand study carcass evaluations were conducted at 13 abattoirs (Stark et al 1998). As reported from other studies, environmental (ventilation, manure management) and management (stocking density, use of feed medication) factors were associated with both the severity and frequency of enzootic pneumonia and pleurisy. An earlier New Zealand study of abattoir lesions conducted from 1986-90 (prior to development of the PigCheck programme) reported the prevalence of enzootic pneumonia to be 45% (Christensen and Cullinane 1990). A study of enzootic pneumonia in abattoir pigs in South Australia was conducted in 1980 (Pointon and Sloane 1984). In this study, 45.1% of lungs had enzootic pneumonia lesions and the authors noted substantial variation in prevalence among the three abattoirs in the study (22.2%, 41.9%, and 71.2%). Prevalence of pleurisy was 14.5% and again there was substantial variation reported among abattoirs. Seropositivity to *M. hyopneumoniae* was highly associated with enzootic pneumonia lesions in this study. In South Australia and

Western Australia, formalized slaughter monitoring services commenced in the mid-1980s (Pointon et al 1987; Mercy and Brennan 1988) based on a surveillance scheme in place in Denmark at the time. Across 157 herds in Western Australia in 1987, approximately 10% of pigs had pleuropneumonia, 20% had pleurisy, and 40% had lesions of enzootic pneumonia.

Antero-ventral pneumonia is not pathognomonic for enzootic pneumonia though clinical signs and infection with *M. hyopneumoniae* are frequently associated with the lesion (Willeberg et al 1984). Several methods for scoring lungs have been described and summarized by previous authors (Sibila et al 2009; Meyns et al 2011). Enzootic pneumonia lesions are thought to resolve approximately two to three months after infection is established (Noyes et al 1990; Sorensen et al 2006; Caswell and Williams 2007), therefore lesions of cranio-ventral pneumonia observed in an abattoir provide evidence of the disease occurring late in finishing. Chronic pleurisy may only be detected for up to three months post-insult (Sorensen et al 2006; Sanchez-Vazquez et al 2011).

While lesions related to respiratory disease are amongst the most prevalent in the current New Zealand data, it appears that the overall frequency of their occurrence is reduced from prior surveys and compares favourably to similar data generated from Europe.

Milk spot lesions were identified as the third most prevalent lesion (9.21%) in the study. The term “milk spots” refers to the whitish-coloured foci that occur in the liver stroma and are associated with a healing wound resulting from the migration of *Ascaris suum* larvae. Ascariasis in pigs has a well-known seasonality based on the temperature-based maturation of larvae inside *A. suum* ova in the environment, the ability of the ova to persist for years in an outdoor environment that cannot be cleaned and disinfected, and the fact that pigs are only raised outdoors during late spring, summer, and fall. Data from English abattoirs collected in 2005 to 2010 showed the prevalence of milk spots to be 4.2% and a time series analysis of the same data showed the prevalence peaked in late summer and early fall, concurrent with the increase in pigs being reared in outdoor environments around this time (Sanchez-Vazquez et al 2012). The same authors confirmed in their study that outdoor farms or the use of bedding materials indoors were risk factors for ascariasis (Sanchez-Vazquez et al 2010). Similar to the situation with lung lesions, few studies of the occurrence of ascariasis lesions in the southern hemisphere are available. However, in a 1990 New Zealand study, milk spots were

observed on 13% of livers that were examined (Christensen and Cullinane 1990). Milk spots only persist for approximately one month post-migration of the larvae making the lesion a sensitive indicator of recent exposure to the parasite (Stewart and Hoyt 2006). Ascariasis in New Zealand pigs occurs at a low level and appears to be decreasing over time. In contrast to the English data, the highest prevalence of ascariasis in the current study was found mid-winter and may be related more to bedding management during the winter months as opposed to any seasonal fluctuations in the infectious load on paddocks.

Most studies of abattoir lesions focus on lung pathology with comparatively fewer studies available that include information on the other lesions that were described in the PigCheck data. The prevalence of ileitis (7%) and mange (13%) in slaughter pigs was previously reported in New Zealand (Christensen and Cullinane 1990), both of which are higher than the estimates reported here.

Routine use of animal disease data generated from lesions identified in pigs delivered to abattoirs has been formally incorporated into farm- or national-level disease monitoring programmes in different parts of the world since at least 1964 (Christensen et al 1994). Systematic collection of abattoir lesion data began in New Zealand in 1974 under a programme run by the Ministry of Agriculture and Fisheries called “Diseases and Defects” (Christiansen and Hellstrom 1979). In this programme, 18 lesions were recorded from slaughter sheep, cattle, pigs, and goats with PigCheck currently taking the place of the now defunct Diseases and Defects programme for pigs.

Data from this study provide insight into the relative contribution of the farm versus the abattoir in the variation of lesion prevalence. Variation in lesions that were more difficult for inspectors to identify (or that simply had a greater degree of normal variation) such as mange and ileitis, were strongly influenced by the abattoir at which the pigs were processed. Easy to identify lesions such as rectal prolapse and various lung pathologies were more strongly influenced by farm factors. These findings will be important in any future revisions of the lesion definitions, for inspector training, and in order for farmers and veterinarians to correctly interpret PigCheck results.

Abattoir monitoring programmes are not without their deficiencies and various authors have described limitations of some of the historical and current programmes. Concerns that have been identified include the fact that the sampling frame is biased given most if not all animals delivered to an abattoir are clinically healthy, that few of the lesions being recorded are pathognomonic for a particular disease thus limiting the specificity

of the surveillance activity, and that the high speed of modern abattoirs makes complete and accurate evaluation of tissues very difficult (Christiansen and Hellstrom 1979). Other authors have suggested limitations related to the sustainability of abattoir surveillance programmes as the willingness of a farmer to pay for the service may decline as overall health of his stock improves, and that visits by veterinarian prompted by abattoir findings may not be timely and in fact may occur after the farmer has already instituted an intervention (Christensen et al 1994). In a study that reviewed the effectiveness of four concurrently operating surveillance systems in the English pig industry, two of which utilized samples or observations at abattoirs, the investigators observed that there existed a general lack of integration of the monitoring and surveillance systems both at the strategic and the operational levels, that there was a lack of routine in-depth analysis of the data, and that there was an unknown level of bias in the data being collected. All of these findings would be important considerations in making future improvements to the programmes (Stark and Nevel 2009).

However, despite their shortcomings there is evidence that abattoir monitoring programmes can be a useful part of an early warning system for animal diseases. Canadian researchers completed a retrospective analysis of abattoir data to determine if there were clues that could have led to early detection of a large outbreak of disease caused by porcine circovirus type 2 in Ontario (Thomas-Bachli et al 2012). The investigators determined that an increasing occurrence of kidney lesions was spatially and temporally related to the outbreak though pneumonia lesions appeared not to be related. In a similar exercise, an investigator from the United States reviewed condemnation data collected by the Food Safety Inspection Service in 2003 and concluded that a 2001 outbreak of erysipelas in Iowa and Minnesota could have been identified up to ten months earlier if automated analysis of the data had been in place (Bush and Engle 2003).

Given the lack of disease specificity when monitoring the occurrence of disease lesions, abattoir monitoring might be considered a form of “syndromic surveillance”. A review of current and recent efforts at veterinary syndromic surveillance defined syndromic surveillance as “one in which the surveillance activity targets general groups of disease, or syndromes” and that a trade-off for this lack of specificity in a good performing system should be an improved timeliness of reporting (Dorea et al 2011). The nature of reporting may vary depending on a programme’s objectives. One expert has suggested the interdisciplinary field encompassing the science and technologies involved in

collection and reporting of infectious disease data from syndromic surveillance might be called “infectious disease informatics” and could take advantage of a range of tools such as data sharing software, geographic information systems, biostatics and data visualization algorithms (Zeng et al 2005). Additional tools for monitoring temporal changes in disease data include statistical process control methods such as use of control charts. Control charts are commonly employed in non-veterinary industries but do not appear to have been readily picked up for analysis of surveillance data (De Vries and Reneau 2010).

Little research has been conducted to assess the utility of abattoir surveillance to the farmer or veterinarian. In a 1985 survey of Canadian farmers and veterinarians, 89.4% said they intended to use the disease information produced by a computerized reporting system of abattoir lesions (Shadbolt et al 1987). These same farmers (50.3%) and veterinarians (57.1%) reported that they would like the information on a monthly basis and that the information be as detailed as possible, including information about disease severity not just disease frequency. However, 56.3% of farmers in the study also disclosed that they actually never discussed the abattoir surveillance results with their veterinarian. In contrast, 60.3% of farmers believed that summary information representing all farms in the country or region should be shared with industry veterinarians.

In summary, the overall prevalence of most lesions recorded in PigCheck for the period 2000 through 2010 was low relative to published data from other countries. Common lung pathologies contributing to lesions such as pneumonia and pleurisy were primarily a function of farm management and were not likely due to variability in lesion recording at different abattoirs. Based on the low frequency of lesions identified in pigs at commercial abattoirs, the health status of the New Zealand pig industry is very good. Pneumonia, pleurisy, and ascariasis are some of the most prevalent conditions which should be focussed on through development of herd health management plans.

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References

***Anonymous.** PigCheck Service Profile. *Asure New Zealand Ltd*, Christchurch, New Zealand, 1999

Blocks GHM, Vernooy JCM, Verheijden JHM. Integrated quality control project: Relationships between pathological findings detected at the slaughterhouse and information gathered in a veterinary health scheme at pig farms. *Veterinary Quarterly* 16, 123-7, 1994

***Bush EJ, Engle MJ.** A comparison of four methods for detecting the July 2002 Erysipelas epidemic. *In Proceedings of: '10th International Symposia on Veterinary Epidemiology and Economics'*. Vina del Mar, Chile Pp 581-4, 2003

***Caswell JL, Williams KJ.** Respiratory system. In: Maxie MG, Jubb KVF (eds). *Pathology of domestic animals*. Pp 591-3. Elsevier Saunders, Edinburgh ; New York, 2007

Christensen J, Ellegaard B, Kirkegaard Petersen B, Willeberg P, Mousing J. Pig health and production surveillance in Denmark: sampling design, data recording, and measures of disease frequency. *Preventive Veterinary Medicine* 20, 47-61, 1994

Christensen NH, Cullinane LC. Monitoring the health of pigs in New Zealand abattoirs. *New Zealand Veterinary Journal* 38, 136-41, 1990

***Christiansen KH, Hellstrom JS.** The collection of data from New Zealand abattoirs and slaughterhouses. In: 2nd International Symposium of the International Society for Veterinary Epidemiology and Economics. Pp 168-76. (Canberra, ACT, Australia) 1979

Davies PR, Bahnson PB, Grass JJ, Marsh WE, Dial GD. Attitudes of veterinarians to a standardized slaughter-monitoring program for pigs. *Journal of the American Veterinary Medical Association* 209, 123-6, 1996

De Vries A, Reneau JK. Application of statistical process control charts to monitor changes in animal production systems. *Journal of Animal Science* 88, E11-E24, 2010

Diggle P. Time series : a biostatistical introduction, Oxford University Press, Oxford, England, 1990

Dorea FC, Sanchez J, Revie CW. Veterinary syndromic surveillance: Current initiatives and potential for development. *Preventive Veterinary Medicine* 101, 1-17, 2011

Elbers ARW, Tielen MJM, Snijders JMA, Cromwijk WAJ, Hunneman WA. Epidemiological studies on lesions in finishing pigs in the Netherlands. I. Prevalence, seasonality and interrelationship. *Preventive Veterinary Medicine* 14, 217-31, 1992

Fablet C, Dorenlor V, Eono F, Eveno E, Jolly JP, Portier F, Bidan F, Madec F, Rose N. Noninfectious factors associated with pneumonia and pleuritis in slaughtered pigs from 143 farrow-to-finish pig farms. *Preventive Veterinary Medicine* 104, 271-80, 2012

Fraile L, Alegre A, Lopez-Jimenez R, Nofrarias M, Segales J. Risk factors associated with pleuritis and cranio-ventral pulmonary consolidation in slaughter-aged pigs. *Veterinary Journal* 184, 326-33, 2010

Jager HC, McKinley TJ, Wood JL, Pearce GP, Williamson S, Strugnell B, Done S, Habernoll H, Palzer A, Tucker AW. Factors associated with pleurisy in pigs: a case-control analysis of slaughter pig data for England and Wales. *PLoS ONE* 7, e29655, 2012

Ljung GM, Box GEP. On a measure of lack of fit in time series models. *Biometrika* 65, 297-303, 1978

***Mercy AR, Brennan CM.** Postweaning Multisystemic Wasting Syndrome (PMWS) - experimental evidence for a transmissible causal agent. *In Proceedings of: '5th Symposium of the International Society for Veterinary Epidemiology and Economics'*. Copenhagen, Denmark Pp 212-4, 1988

Meyns T, Van Steelant J, Rolly E, Dewulf J, Haesebrouck F, Maes D. A cross-sectional study of risk factors associated with pulmonary lesions in pigs at slaughter. *Veterinary Journal* 187, 388-92, 2011

Neumann EJ, Pearson AB, Sanson RL, Nicoll KJ, Clement FL. The frequency and distance of movements of pigs and semen between commercial and non-commercial piggeries in New Zealand. *New Zealand Veterinary Journal*, 1-10, 2012

Noyes EP, Feeney DA, Pijoan C. Comparison of the effect of pneumonia detected during lifetime with pneumonia detected at slaughter on growth in swine. *Journal of the American Veterinary Medical Association* 197, 1025-9, 1990

Olsson SO, Baekbo P, Hansson SO, Rautala H, Osteras O. Disease recording systems and herd health schemes for production diseases. *Acta veterinaria Scandinavica. Supplementum* 94, 51-60, 2001

Pointon AM, Sloane M. An abattoir survey of the prevalence of lesions of enzootic pneumonia of pigs in South Australia. *Australian Veterinary Journal* 61, 408-9, 1984

Pointon AM, Heap P, McCloud P. Enzootic pneumonia of pigs in South Australia--factors relating to incidence of disease. *Australian Veterinary Journal* 62, 98-101, 1985

***Pointon AM, Farrell M, Cargill CF, Heap P.** A pilot pig health scheme for Australian conditions. *In Proceedings of: 'Refresher Course in Pig Medicine*

(Number 95)'. Sydney, New South Wales, Australia Pp 743-77. (Postgraduate Committee in Veterinary Science, University of Sydney), 1987

***Pointon AM, Davies PR, Bahnson PB.** Disease surveillance at slaughter. In: Straw BE, D'Allaire S, Mengeling WL, Taylor DJ (eds). *Diseases of Swine*. Pp 1111-32. Iowa State University Press, Ames, Iowa, USA, 1992

Sanchez-Vazquez MJ, Smith RP, Kang S, Lewis F, Nielen M, Gunn GJ, Edwards SA. Identification of factors influencing the occurrence of milk spot livers in slaughtered pigs: A novel approach to understanding Ascaris suum epidemiology in British farmed pigs. *Veterinary Parasitology* 173, 271-9, 2010

Sanchez-Vazquez MJ, Strachan WD, Armstrong D, Nielen M, Gunn GJ. The British pig health schemes: integrated systems for large-scale pig abattoir lesion monitoring. *The Veterinary record* 169, 413, 2011

Sanchez-Vazquez MJ, Nielen M, Gunn GJ, Lewis FI. National monitoring of Ascaris suum related liver pathologies in English abattoirs: a time-series analysis, 2005-2010. *Veterinary Parasitology* 184, 83-7, 2012

Shadbolt PV, Mitchell WR, Blackburn DJ, Meek AH, Friendship RM. Perceived Usefulness of the Collection of Subclinical and other Disease Entities Detected at Slaughter. *The Canadian veterinary journal. La revue veterinaire canadienne* 28, 439-45, 1987

Sibila M, Pieters M, Molitor T, Maes D, Haesebrouck F, Segales J. Current perspectives on the diagnosis and epidemiology of Mycoplasma hyopneumoniae infection. *Veterinary Journal* 181, 221-31, 2009

***Sorensen V, Jorsal SE, Mousing J.** Diseases of the respiratory system. In: Straw BE, Zimmerman JJ, D'Allaire S, Taylor DJ (eds). *Diseases of Swine*. Pp 149-77. Blackwell Publishing, Ames, Iowa, USA, 2006

Stark KD, Pfeiffer DU, Morris RS. Risk factors for respiratory diseases in New Zealand pig herds. *New Zealand Veterinary Journal* 46, 3-10, 1998

Stark KD. Epidemiological investigation of the influence of environmental risk factors on respiratory diseases in swine--a literature review. *Veterinary Journal* 159, 37-56, 2000

Stark KD, Nevel A. Strengths, weaknesses, opportunities and threats of the pig health monitoring systems used in England. *The Veterinary Record* 165, 461-5, 2009

***Stewart TB, Hoyt PG.** Internal parasites. In: Straw BE, Zimmerman JJ, D'Allaire S, Taylor DJ (eds). *Diseases of Swine*. Pp 901-14. Blackwell Publishing, Ames, Iowa, USA, 2006

Thomas-Bachli AL, Pearl DL, Friendship RM, Berke O. Suitability and limitations of portion-specific abattoir data as part of an early warning system for emerging diseases of swine in Ontario. *BMC Veterinary Research* 8, 3, 2012

Willeberg P, Gerbola MA, Petersen BK, Andersen JB. The Danish pig health scheme: Nation-wide computer-based abattoir surveillance and follow-up at the herd level. *Preventive Veterinary Medicine* 3, 79-91, 1984

***Zeng D, Chen H, Lynch C, Eidson M, Gotham I.** Infectious disease informatics and outbreak detection. In: Chen H, Fuller SS, Friedman C, Hersh W (eds). *Medical informatics: Knowledge management and data mining in biomedicine*. Pp 359-98. Springer, New York, NY, 2005

Tables

Table 20. Description of 22 lesions reported by PigCheck abattoir-based disease surveillance system.

Lesion name	Definition
Arthritis	Swelling and/ or excess fluid associated with tarsal, metatarsal, carpal, or metacarpal joints; may include suppurative or non-suppurative inflammatory responses.
Broken back	Vertebral fracture caused by inappropriate electrical stunning conditions.
Emaciation[a]	Subjective assessment based prominent bony protuberances and ribs.
Full gut[a]	Stomach contains appreciable (> 250 mL) quantity of feed or ingesta.
Ileitis	Grossly visibly thickening or haemorrhage of ileal wall.
Kidney condition	Presence of haemorrhage, white spots, or chronic swelling of kidney(s).
Mange	Red papules, predominantly on ears, belly, or rump/ scrotum.
Milk spot	Presence of white spots on surface of liver as a result of roundworm larvae migration.
Other lesions	Miscellaneous occurrence of infectious or non-infectious disease processes not otherwise listed.
Pericarditis[a]	Excessive accumulation of fluid around the heart with or without pericardial thickening and adhesion.
Pleurisy	Fibrinous adhesion between the lung and thoracic wall, unassociated with an active pneumonic process.
Pleuropneumonia	Pneumonia associated with inflammation or fibrinous response of the pleura.
Pneumonia	Pneumonic lesions not otherwise considered to meet the definition of "Antero-ventral pneumonia".
Antero-ventral pneumonia[b]	Pneumonic lesions restricted to the antero-ventral aspect of the lung; typically associated with enzootic pneumonia.
Rectal prolapse	Exterior prolapse of the rectal mucosa.
Pyogenic lesion	Presence of external or internal abscess(es).
Septicaemia	Generalized acute (oedematous, haemorrhagic) lymphadenopathy.
Tuberculosis-like lesion	Enlargement of lymph nodes associated with caseous infiltrates.
Wound	Laceration of the skin.
Bruising	Excoriation or bruising of the skin.

[a] Insufficient data available to include in time series analysis

[b] Pneumonia due to infection with *Mycoplasma hyopneumoniae*

Table 21. Summary of lots of pigs delivered to abattoirs from July 1997 through December 2010.

Abattoir ID	Number of lots (proportion)		Total pigs delivered	Mean lot size	Number of suppliers
A	40,493	(33%)	2,091,855	51.7[a]	159
B	10,413	(8%)	545,168	52.3[a]	65
C	29,993	(24%)	1,394,805	46.5[b]	28
D	32,314	(26%)	1,635,454	50.6[c]	53
E	11,194	(9%)	553,382	49.4[c]	22
Summary	124,407	(100%)	6,220,664	50.0	280[d]

[a,b,c] Differences between means in each row with different subscripts are significant (Tukey's HSD, $p < 0.05$).

[d] Total number of unique suppliers to all abattoirs. Some suppliers delivered pigs to more than one abattoir.

Table 22. Estimated overall prevalence of 17 lesions reported by PigCheck from 2000 through 2010. Th trend for each lesions is presented including the autoregressive, integrated, and moving average (ARIM analysis.

				Trend
Lesion name	**Months[a]**	**Prevalence (95% CI)**		**Annual**
Arthritis	132	1.85%	(1.83% - 1.88%)	+ 0.06%
Broken back	132	0.62%	(0.6% - 0.63%)	- 0.03%
Ileitis	132	0.55%	(0.51% - 0.58%)	+ 0.10%
Kidney condition	112[b]	0.15%	(0.15% - 0.16%)	- 0.01%
Mange	132	3.63%	(3.58% - 3.68%)	+ 0.23%
Milk spots	132	9.21%	(9.09% - 9.32%)	- 0.54%
Other lesions	132	0.08%	(0.07% - 0.09%)	N/A
Pleurisy	132	3.13%	(3.1% - 3.16%)	+ 0.29%
Pleuropneumonia	132	11.43%	(11.33% - 11.53%)	- 0.97%
Pneumonia	132	0.91%	(0.89% - 0.94%)	- 0.12%
Antero-ventral pneumonia	132	17.57%	(17.45% - 17.7%)	- 0.73%
Rectal prolapse	132	5.77%	(5.7% - 5.84%)	- 0.33%
Pyogenic lesion	132	0.01%	(0% - 0.01%)	N/A
Septicaemia	132	2.69%	(2.65% - 2.73%)	- 0.04%
Tuberculosis-like lesion	132	0.01%	(0.01% - 0.01%)	- <0.01%
Wound	132	0.95%	(0.92% - 0.98%)	+ 0.17%
Bruising	132	1.35%	(1.33% - 1.37%)	- 0.04%

[a] Data available from January 2000 through December 2010

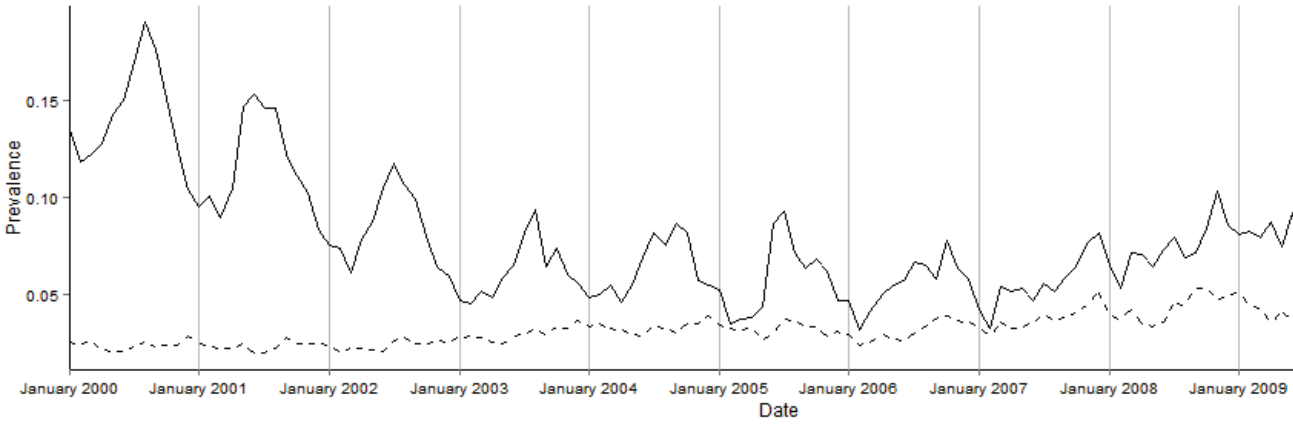
[b] Data available from September 2001 through December 2010

Table 23. Prevalence of positive farms for 17 lesions recorded by PigCheck from 2000 through 2010 among 279 New Zealand pig farms.

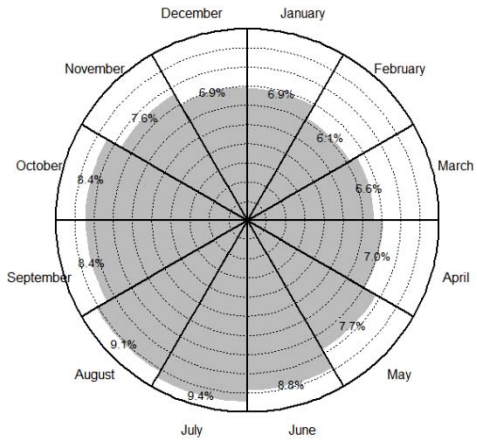
Lesion name	Prevalence (95% CI)	
Arthritis	86.4%	(81.8% - 90.2%)
Broken back	75.3%	(69.8% - 80.2%)
Ileitis	36.2%	(30.6% - 42.1%)
Kidney condition	64.2%	(58.2% - 69.8%)
Mange	84.2%	(79.4% - 88.3%)
Milk spots	91.8%	(87.9% - 94.7%)
Other lesions	57.7%	(51.7% - 63.6%)
Pleurisy	86.7%	(82.2% - 90.5%)
Pleuropneumonia	90.0%	(85.8% - 93.2%)
Pneumonia	71.7%	(66.0% - 76.9%)
Antero-ventral pneumonia	88.8%	(83.8% - 91.7%)
Rectal prolapse	86.7%	(82.2% - 90.5%)
Pyogenic lesion	9.0%	(5.9% - 12.9%)
Septicaemia	84.6%	(79.8% - 88.6%)
Tuberculosis-like lesion	24.4%	(19.5% - 29.8%)
Wound	71.0%	(65.3% - 76.2%)
Bruising	85.7%	(81.0% - 89.6%)

Figures

(A)



(B)



(C)

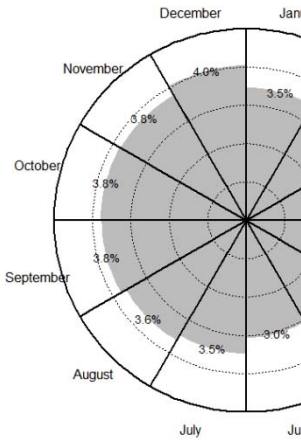


Figure 17. Time series plot (A) of the prevalence of milk spots (solid line) and pleurisy (dashed line) lesi 1999 through 2010. Mean prevalence of milk spots (B) and pleurisy (C) by month shown in polar plots

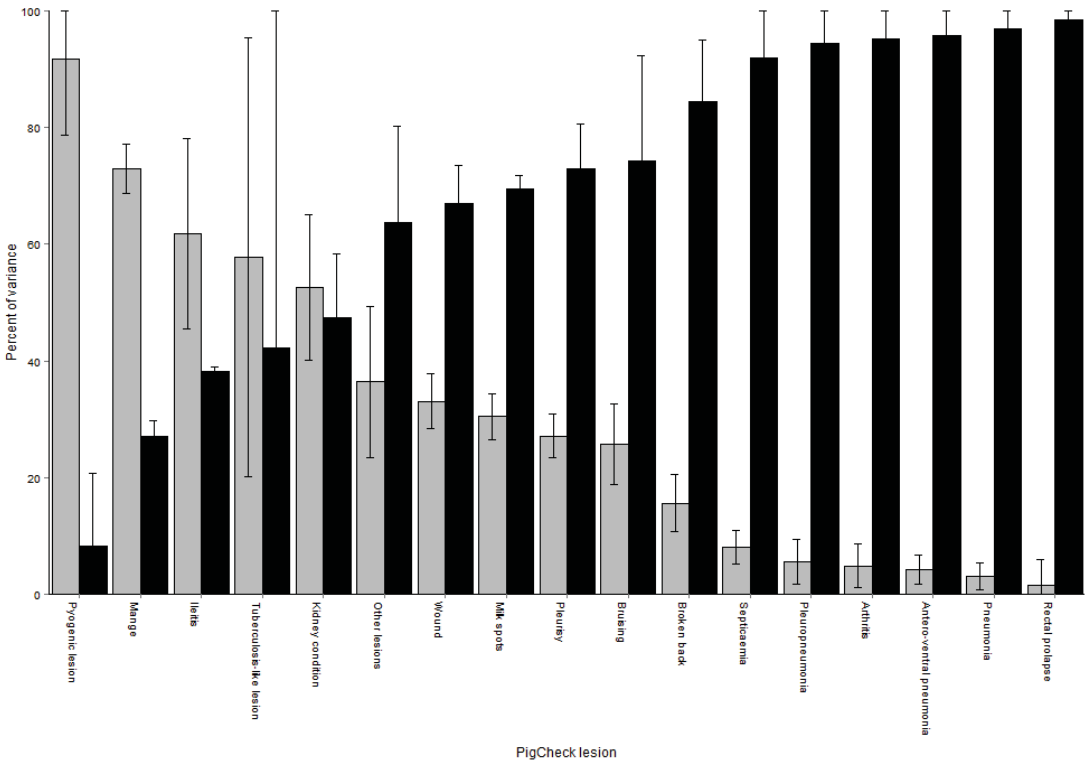


Figure 18. Proportion of explainable variance in lesion prevalence attributable to farm (black bars) or abattoir (grey bars) for 17 lesions reported by PigCheck from 1999 through 2010. The information was derived from PigCheck data collected at five abattoirs and represents 85,281 observations from 322 New Zealand farms.

Chapter 7. Use of Investment Logic Mapping for strategic biosecurity planning in the New Zealand pig industry

Abstract

AIMS: A project was undertaken to establish a biosecurity and surveillance strategy for the New Zealand pig industry.

METHODS: A formal investment decision-making tool called Investment Logic Mapping (ILM) was utilized in a facilitated discussion format with the Board of Directors at the New Zealand Pork Industry Board to establish biosecurity priorities for the industry. Investment Logic Mapping is purposefully designed to focus the decision-makers on the benefits of a potential investment rather than simply acting as a business case for justifying a particular solution which appears to be most feasible. Spreadsheet modelling was then used to estimate the cost of a comprehensive exotic disease surveillance system in the New Zealand industry.

RESULTS: Participants in the ILM process identified three problems for which solutions and benefits were desired from making an industry investment in biosecurity: Changing pork IHS (Import health standard) has put the industry at increased risk of PRRS and other exotic diseases, no on-going surveillance for exotic diseases makes rapid detection of an incursion unlikely, and a philosophical shift in MPI (Ministry of Primary Industries) to user-pays biosecurity resulting in an increased need for cash investment in biosecurity by the industry. A single strategy 'improve surveillance for exotic diseases of pigs' was determined to contribute most substantially to achieving the three benefits. In response to this finding, spreadsheet modelling of potential surveillance activities was completed. A combination of abattoir-based serologic testing, intensive monitoring of genetic suppliers, subsidizing of diagnostic laboratory services, and aggregated analysis of the PigCheck abattoir lesion database were recommended as components of a surveillance system that could be established for approximately $0.50 per pig annually.

CONCLUSIONS: Investment Logic Mapping was a useful tool for development of a national biosecurity strategy in the New Zealand pig industry. As part of a biosecurity strategy, surveillance for exotic diseases could be implemented for approximately $0.50 per pig annually; this cost could be equitably shared by all parties that would be expected to benefit from improved surveillance including farmers, government, and industries allied with New Zealand pig production. Non-commercial pigs present a particular risk for exotic disease introduction and this risk will need to be managed by government.

CLINICAL RELEVANCE: Improved surveillance for exotic diseases in the pig industry will increase the likelihood of rapid detection and control of a disease incursion.

KEY WORDS: Pig, Epidemiology, Infectious Disease Transmission, Biosecurity, Population Surveillance

Abbreviations

BMP	Benefit Management Plan
EADRA	Emergency Animal Disease Response Agreement
GIA	Government-Industry Agreement
IHS	Import health standard
ILM	Investment Logic Mapping
KPI	Key performance indicators
MAF	Ministry of Agriculture and Forestry
MPI	Ministry of Primary Industries (formerly MAF)
MQM	MAF Quality Management
NZ Pork	New Zealand Pork Industry Board
NZVP	New Zealand Veterinary Pathology Ltd
OIE	World Organisation for Animal Health
PMWS	Post-weaning multisystemic wasting syndrome
PRRS	Porcine reproductive and respiratory syndrome

Introduction

Background

National-level surveillance for animal diseases occurs in nearly every country in the world that has a well-developed animal agricultural sector. In particular, those countries wishing to either import or export animals or animal products (meat, semen, eggs, animal proteins, milk, etc.) are often obliged to undertake disease surveillance to routinely confirm that a particular disease does not exist in their country. Establishing credible evidence that a disease does not exist in a country has the potential of opening (or maintaining) export opportunities for that country and may also form the basis for refusing to accept imports from other countries that are not able to prove their livestock industry(s) have an equivalent or better health status.

The organisation that maintains a global repository of countries and their generally recognized animal disease statuses is the World Organisation for Animal Health (OIE). The OIE was established through an international agreement signed in 1924. The OIE is recognised as a reference organisation by the World Trade Organization and as of 2011 had a total of 178 Member Countries. The OIE's financial resources are principally derived from compulsory annual contributions from Member Countries.[12]

The mission of OIE is to provide resources, technical guidelines, and act as a consensus-building organisation with a focus primarily on 80 diseases[13] having significant potential for transboundary spread, or having important economic or zoonotic consequences. While countries are free to adopt their own disease surveillance programmes, OIE provides guidelines for establishment of surveillance programmes for many of these 80 diseases in order to assist a country in proving their freedom from a disease, or recommending what surveillance might be required for a country to re-establish a 'free status' after an incursion of a listed disease.

A number of animal diseases exist across the globe for which a country may have interest in including in their national surveillance programme, despite their not being classified as an 'OIE Listed Disease'. Many examples of surveillance programmes for both listed and non-listed diseases exist around the world. However, comprehensive descriptions of national surveillance programmes are notoriously difficult to locate though individual components of such programmes are more widely available.[14,15,16,17]

[12] http://www.oie.int/, accessed December 24, 2012.
[13] http://www.oie.int/animal-health-in-the-world/oie-listed-diseases-2012/, accessed December 24, 2012.
[14] http://vla.defra.gov.uk/science/sci_rs_intro.htm, accessed December 24, 2012.

High-quality surveillance for animal diseases requires a substantial financial investment in diagnostic testing, sampling logistics, and reporting. Determining who is responsible for this financing provides fodder for an on-going debate in the public policy arena and New Zealand is no exception. Traditional thinking might suggest that surveillance for any animal disease that is exotic to a country (and for which there is an interest in that country remaining free of that disease) be paid from public funds. In the context of a country such as New Zealand whose national economy is heavily dependent on export of animal products (Anonymous 2003), a case can readily be made that the entire cost of the surveillance programme should be supported through public funds for trade-limiting diseases such as foot and mouth disease (FMD). However, for other diseases such as post-weaning multisystemic wasting syndrome (PMWS), the determination of who should pay for surveillance (or indeed, the cost of eradication) is less clear. Internationally, there appears to be steady movement toward public policy that shifts an increasing share of the cost of government-sponsored national programmes to the primary beneficiaries of those programmes, rather than the secondary (or potential) beneficiaries (Larner 2009). Animal disease surveillance programmes have not been immune from this shift in policy and Australia provides an excellent and well-documented example in their AUSVETPLAN.[18] While focussed more on disease investigation and response rather than surveillance, AUSVETPLAN is based on a contractual arrangement known as the Emergency Animal Disease Response Agreement (EADRA) between the Australian Commonwealth, state and territory governments, and livestock industry groups and describes their preferred approach to an outbreak of approximately 29 diseases exotic to Australia. AUSVETPLAN is comprised of a series of manuals that set out the various roles, responsibilities and policy guidelines for agencies and organisations involved in an exotic disease response. Importantly, AUSVETPLAN and EADRA clearly identify the cost-sharing burden for a response associated with an outbreak of any of the diseases (Anonymous 2001); the government ('public good') share for the four categories of animal ranges from 20 to 100%. Recently the New Zealand Government, led by the Ministry for Primary Industries (MPI) through a joint industry working group called the Surveillance and Incursion

[15] http://www.aphis.usda.gov/vs/nahss/index.htm, accessed December 24, 2012.
[16] http://www.animalhealthaustralia.com.au/programs/disease-surveillance/national-animal-health-information-system/, accessed December 24, 2012.
[17] http://www.biosecurity.govt.nz/pests-diseases/animals/surveillance.htm, accessed December 24, 2012.
[18] http://www.animalhealthaustralia.com.au/programs/emergency-animal-disease-preparedness/ausvetplan/, accessed December 24, 2012.

Response Working Group, has initiated work that will establish the cost-sharing and decision-making obligations for animal disease surveillance and response; this effort is referred to as the Government-Industry Agreement (GIA) initiative (Anonymous 2009a). The GIA will be under-pinned by industry signature to a Deed of Agreement expected to be completed in early 2013.[19] The Agreement will cover pests and diseases nominated by industry groups and found to be of sufficient interest such that an industry would be prepared to invest in a readiness or response programme for that disease. The GIA will initially focus only on diseases that are not present in New Zealand, though endemic pests or diseases may be covered under GIA in the future. While the GIA specifically refers to 'readiness' *sic* surveillance, the GIA unfortunately does not feature at all in a major MPI strategy document that was recently released and describes the national strategy for animal disease surveillance (Anonymous 2009b) making it unclear at this time to what extent surveillance activities will be covered under GIA.

Current surveillance activities

No active surveillance programme for exotic diseases is currently in place in the New Zealand pig industry. Periodic testing for exotic diseases on individual herds or animals does however occur as a result of suspicious clinical or laboratory reports that are subsequently forwarded to MPI by farmers, veterinarians, diagnostic laboratories, or the general public. The last statistically valid proof-of-freedom surveillance conducted in the New Zealand pig industry for any exotic diseases was for transmissible gastroenteritis, porcine respiratory coronavirus, and porcine reproductive and respiratory syndrome (PRRS) in 1996 (Motha et al 1997) and again for in 2004 for PRRS (Stone and Kittelberger 2004).

Trade in animal related risk goods (animals and animal products) is important to New Zealand and not unexpectedly, clashes between policy on trade (IHS; import health standards) and domestic biosecurity (surveillance, animal movements, animal identification, etc.) are frequent. Recent examples of this conflict have been widely debated and include export of New Zealand apples to Australia and the risk of introducing fire blight (*Erwinia amylovora*) into that country (Knight 2005), importation of Australian honey into New Zealand and the risk of introducing *Paenibacillus alvei* through that activity (Oughton et al 2009), and the importation of fresh pork into New Zealand from countries known to be endemically infected with

[19] http://www.biosecurity.govt.nz/biosec/new-post-border/gia, accessed December 24, 2012.

PRRS virus (Neumann et al 2007b; Neumann and Morris 2008; O'Neil 2008). By charging New Zealand's Ministry of Primary Industries (MPI) with the concurrent and often contradictory duties of *'maximising export opportunities for the primary industries [and] protecting New Zealand from biological risk'*[20] a check and balance across these two important functions is compromised making appropriately formulated and debated policy on biosecurity a very difficult task.

Abattoir surveillance

Outside of a formal and compulsory disease surveillance system in the pig industry, several components of an informal or voluntary surveillance system are in place. A farmer-funded programme called PigCheck that records the occurrence of ante- and post-mortem lesions of production limiting diseases on pig carcasses arriving at commercial abattoirs has been in place since 1997 (Neumann et al Submitted (2012)). In PigCheck, the results of carcass assessments are recorded in a near real-time database that is accessible online to the farmer and his designated veterinarian but until recently, no national reporting of the data collected from PigCheck has been completed (Neumann et al Submitted (2012)). PigCheck data covers more than 95% of the country's pig production from commercial farms and real-time analysis of the data across all farms could prove useful as part of a national syndromic surveillance programme.

On-farm production records

Computerized production records are widely used on New Zealand commercial pig farms.[21] In particular, nearly every commercial pig farm with breeding sows in New Zealand is managed with the assistance of computerized records and for those herds with more than 125 sows, all are using a single programme called Elite Herd.[22] As with PigCheck, it appears there may be sufficient data available from computerized records of commercial breeding herds to make aggregation and analysis of the data across farms useful as part of a syndromic surveillance programme. By contrast, use of computerized record systems for managing the rearing of pigs post-weaning is much less common as evidenced by work done in New Zealand following the widespread outbreak of PMWS in the south island in 2006 (Neumann et al 2007a). To mitigate the effect of the PMWS on the affected farms after the initial outbreak, porcine circovirus type 2 vaccination

[20] http://mpi.govt.nz/, accessed December 24, 2012.
[21] Skorupski, M. Personal communication, December 23, 2012.
[22] http://www.eliteherd.com/, accessed December 24, 2012.

was initiated on a number farms. The efficacy of the vaccination was measured on a representative sample of these farms through an analysis of post-weaning mortality data. As noted in the published report of this study, a number of farms that could have contributed data to this study had to be excluded due to their lack of post-weaning records or unreliable recording of data that was collected (Neumann et al 2009). None of the data from this study came from computerized record systems.[23] The less intensive use of computerized records across the population of post-weaning pigs makes aggregation and analysis of this information difficult and much less reliable than analysis of data collected from the breeding herds. Despite the well-known positive effects of raising pigs in an all-in all-out pig flow system, there remains a number of New Zealand farms that have not adopted the technology due to their small size or facility constraints; use of continuous flow pig production further compromises the ability to collect high-quality post-weaning production data.

Syndromic surveillance at commercial veterinary diagnostic laboratories

Prior to 1998, MAF employed a large staff of animal production advisors and maintained a network of veterinary diagnostic laboratories that collectively were referred to as MAF Quality Management (MQM). MAF Quality Management provided services directly to farmers and veterinarians at government expense giving the Ministry ready access to both syndromic and diagnostic test-based information on the health of the country's livestock and provided an important tool for disease surveillance. However, in 1998 the MQM operations were divested into two state owned enterprises to be operated under a full cost-recovery model: AgriQuality (responsible for biosecurity, surveillance and laboratory services) and AsureQuality (responsible for meat inspection). For several years, both the supplier of laboratory services (AgriQuality) and its customers (farmers and veterinarians) made adjustments in their delivery (or use) of these services in order to accommodate necessary changes in pricing associated with a full cost-recovery diagnostic system. A result of this adjustment at the time was a dramatic decrease in diagnostic laboratory case load. In 2002, the diagnostic laboratories being operated by AgriQuality were sold to a private company trading as Gribbles Veterinary Pathology NZ Pty; in the same year Gribbles made a further purchase of a private laboratory called Alpha Scientific making them the only significant supplier of veterinary diagnostic laboratory services in New Zealand at the

[23] Neumann, E. Unpublished data.

time. In 2004, Massey University along with private partners responded to this situation by establishing a company called New Zealand Veterinary Pathology Ltd (NZVP) that could provide additional diagnostic services to the market. During this period of change, MAF used its authority to establish an approved list of laboratories[24] and published quality standards (Anonymous 2004) in an effort to maintain links with this important source of passive surveillance data. These approved laboratories were (and still are) required to produce quarterly reports of diseases or syndromes identified through their clinical caseloads for use by MAF. Information from these quarterly reports is summarized and published in MAFs 'Surveillance' magazine[25] and supports New Zealand's annual reports to OIE. As only summary information from this programme is available, its scope, effectiveness, value, and utility has not been thoroughly reported though at least one case study of cattle abortions and respiratory disease using data from this system has been published (Stone 2007). At the current time, Gribbles is operating five laboratories and NZVP is operating three laboratories, across the north and south islands. In addition to these eight private laboratories, MPI maintains its own Investigation and Diagnostic Centre at the National Centre for Biosecurity and Infectious Disease in Wallaceville for the purpose of investigating and diagnosing suspected exotic diseases of animals. New Zealand's freedom from many globally important pig pathogens currently results in limited use of these laboratories by veterinarians that specialize in pig medicine and consequently, their use in a passive syndromic disease surveillance programme in the pig industry will need further consideration.

In order to improve the pig industry's preparedness for detection and management of an exotic disease introduction, a strategic planning process was undertaken to establish an industry biosecurity plan and develop a method for cost-effective exotic disease surveillance.

Methods

Strategic planning for biosecurity in the pig industry

Biosecurity features prominently in the New Zealand pig industry as evidenced by its leading position in the industry's future-proofing strategy adopted at the 2011 annual general meeting of NZ Pork (Anonymous 2011): *'Fundamental to future-proofing*

[24] MAF Biosecurity Authority Standard for Approved Veterinary Diagnostic Laboratories, August 8, 2001 (no longer available).

[25] http://www.biosecurity.govt.nz/publications/surveillance/index.htm, accessed December 23, 2012.

farming for New Zealand's commercial pork producers is maintaining and cherishing the very favourable health status of New Zealand's pig herd – a status which confers significant benefits in terms of welfare, productivity and industry perception.' To further elucidate an operational plan around this biosecurity strategy, a planning tool known as Investment Logic Mapping (ILM) was utilized in order to establish a consensus view of the organisation's Board of Directors on the topic.

Investment Logic Mapping is a component of the Investment Management Standard developed by the State Government of Victoria's Department of Treasury and Finance (Australia) around 2004.[26] At the time there was a general recognition in the Victorian government that decision-making processes had become overly outcome-focussed with the '*unintended consequence of disengaging the key decision-makers, and made solutions the major focus of investments rather than the benefits those solutions were expected to deliver.*'[27] In other words, determining whether an investment should be made had become focussed on study of an available solution, at the expense of focussing on the benefits that would be achieved by implementing a chosen solution. The Standard has evolved as an alternative to other investment decision tools such as SWOT analysis (Strengths, Weaknesses, Opportunities and Threats), SOAR analysis (Strengths, Opportunities, Aspirations and Results), Porter's Five Forces analysis, VRIO analysis (Value, Rarity, Imitability, and Organization), PEST analysis (Political, Economic, Socio-cultural, and Technological environment), and CORE analysis (Capital investment, Ownership involvement, Risk factors, and Exit strategy) that tend to be overly complicated and focus on risk management rather than potential benefits. Investment Logic Mapping is based on three fundamental principles: First, knowledge is best achieved through an informed discussion that brings together those people with the most knowledge of a subject; second, if a need is truly important across an organisation then the logic underpinning any investment in that need should be simple to explain using language and concepts understood by anyone; and third, that the benefits contributed to the organisation by every investment should be easily described. Despite its simplicity, ILM appears to have had little uptake outside Australia though as recently as August 2012, the New Zealand Treasury specifically advocated for the use

[26] http://www.dtf.vic.gov.au/CA25713E0002EF43/pages/investment-management, accessed December 23, 2012.
[27] http://www.dtf.vic.gov.au/CA25713E0002EF43/pages/investment-management-theory-behind-the-ims, accessed December 24, 2012.

of ILM in preparing business cases for New Zealand government investments (Anonymous 2012).

In light of the fact a long-term biosecurity strategy (including surveillance) for the pig industry will need to be developed alongside GIAs, ILM was an appropriate method for determining how NZ Pork should invest in biosecurity and disease surveillance. Over two NZ Pork Board meetings during 2012, a discussion of the organisation's investment in biosecurity was facilitated using methods and templates developed previously by the State Government of Victoria's Department of Treasury and Finance (Australia).

Exotic disease surveillance

Methods for determining the sample size required to establish the absence of disease in a population of animals, at a given level of certainty, have been described previously for simple one-stage (Cannon and Roe 1982) and two-stage sampling procedures (Cameron and Baldock 1998b, 1998a; Ziller et al 2002). These methods have been widely adopted around the world and have served as the basis for population sampling algorithms as part of successful national pig disease surveillance (or eradication) programmes for Aujeszky's Disease (Anderson et al 2008), PRRS (Garner et al 1997), transmissible gastroenteritis and porcine respiratory coronavirus (Motha et al 1997), and others.

Receiving less attention has been development of a sampling strategy that incorporates prior knowledge about the disease status of a population to inform the requirements for future sampling efforts. In the absence of this type of strategy, the confidence one achieves by sampling a population at a rate that will provide '95% confidence that disease is present at less than 1% prevalence' logically will decline every day after the sampling has occurred. Theoretically, one would need to sample the same number of animals (and herds) every day to maintain confidence in being disease free. However, common sense suggests that if you have prior knowledge that a population was disease free 'yesterday', fewer samples would need to be tested 'the next day' in order to maintain the same confidence in disease freedom. Bayesian-type methods for estimating disease prevalence (Johnson et al 2004; Branscum et al 2006) and for combining national surveillance data (Martin et al 2007a; Martin et al 2007b; Martin 2008; Hernandez-Jover et al 2011) have been published in an effort to address this problem. While these methods serve as a useful means of integrating prior knowledge about population disease status into an estimate of the confidence of disease freedom, the methods have not yet been expanded to assist the user in determining the sampling frequency required to achieve an on-going proof of disease freedom.

Based on the exotic disease surveillance opportunities for New Zealand pigs described above, a surveillance plan using both traditional and modified-Bayesian sampling approaches was developed. Results from the strategic biosecurity planning process undertaken by NZ Pork and knowledge gained through previous study of the industry were combined to identify practical and effective components of an exotic disease surveillance programme for the New Zealand pig industry.

Sample size estimates and costs for the various components of a surveillance programme were determined using the combination of a computer spreadsheet and a computerized statistical programme (EpiR package; R Development Core Team, 2011; R Foundation for Statistical Computing, Vienna, Austria). Given the current industry interest in PRRS virus, the sample size and costings were based on use of a commercial ELISA for detection of anti-PRRS virus antibodies (PRRS X3 Ab Test; IDEXX Laboratories, Westbrook, Maine, USA) which has an estimated diagnostic sensitivity of 99% and specificity of 98%.

For modelling purposes, it was assumed that the New Zealand commercial pig industry was comprised of 200 herds, each having an average inventory of 1,300 growing pigs and 170 breeding sows. For surveillance components that involved abattoir-based blood sampling, supplies and labour were costed at $4.00 per sample; farm-based blood sampling and supplies and labour were costed at $15.00 per sample. Laboratory ELISA testing was estimated to cost $6.00 per sample with an allowance of $12.00 per sample for re-testing presumptive positive samples. Additional costs for transporting samples to a laboratory were included when appropriate. To manage the surveillance programme on behalf of the industry, a 0.6 full-time equivalent staffing position was included as a cost in the model.

Results

Strategic planning

Investment Logic Mapping

As described above, the objective of ILM was to focus the investor on the benefits that were expected to occur from making an investment. Prior to undertaking the described planning effort, NZ Pork had an undefined strategy for guiding their investment in biosecurity and this resulted generally in reactive management of problems rather than having a planned, prospective approach that could anticipate problems ahead of time and thereby provide a means for minimizing their effect. The ILM for biosecurity

investment by NZ Pork is shown in Figure 19 on Page 249 and represents the work of their Board members and the NZ Pork technical staff during two facilitated discussions. An ILM is first read down the shaded 'Problem' column whereby a prioritized list of problems related to biosecurity is presented; the percentages associated with each problem represent the relative importance of each problem. To the right are the 'Benefits' to be achieved by solving the problems and may have a 'many-to-one' relationship with the items in the problem list. The ILM tool forces the user to consider the relative importance of each problem separately from the relative benefits that are expected to be achieved by solving each problem; this feature makes an organisation very aware of situations whereby it is spending a lot of time or resources on a problem when the resulting expected benefit is not appropriately matched in size.

The investment plan in Figure 19 on Page 249 is meant to apply broadly across various biosecurity problems but given the importance of PRRS virus at the current time, PRRS features conspicuously in the current strategy. A significant change to the IHS for fresh pork was proposed by MPI in the late 2000's and this change was believed by NZ Pork to increase the risk of PRRS virus being introduced into New Zealand (Neumann et al 2007b). The process of examining the risk related to the proposed change to the IHS has been on-going since at least 2006 when the initial risk assessment was published by MPI and continues even now (late 2012) as the subject of a legal dispute between MPI and NZ Pork in the New Zealand Court of Appeal.[28]

Three problems were identified by the Board through their first ILM-based discussion (Figure 19, Page 249). Firstly, the Board came to realize that the introduction of PRRS virus into New Zealand was not a primary problem that required a solution. The specific problem related to the proposed changes to the IHS was that the 'Changing pork IHS has put the industry at increased risk of PRRS and other exotic diseases' which, if occurred, would dramatically reduce the benefits being realized by farmers in rearing pigs in a very high-health status industry. More traditional strategic planning around the IHS issue might have resulted in the problem being stated as 'the IHS was established without appropriate consideration of the relevant science around PRRS virus transmission'. Stated in this way, very predictable solutions such as 'identify alternative science that is contrary to the science supporting MPI's position', 'fund research that will generate data supportive of NZ Pork's position', and 'implement a public relations

[28] The New Zealand Pork Industry Board v The Director General of the Ministry of Agriculture and Forestry (case number CA282/2012), hearing November 28, 2012.

campaign intended to get New Zealand citizens to actively question MPI's position on the issue' might then have been proposed; in fact all of these solutions (and others) were undertaken by NZ Pork to some effect. However, when the problem was evaluated using ILM to focus the Board on the benefits hoped to be achieved by investing in the problem, additional novel strategies and solutions came to light as shown in Figure 19 on Page 249. Second, a problem stated as 'No on-going surveillance for exotic diseases makes rapid detection of an incursion unlikely' was identified. While related to the first problem, it is distinct in that the main benefit to be achieved by solving this problem was minimizing the consequences of an incursion, and which would only be realized in the event that the first problem actually occurred. In this light, it stands to reason that the strategic responses and resulting solutions devised for the two problems are also distinctly different. The third problem identified by the Board was more insidious than the first two and was stated as a 'Philosophical shift in MPI to user-pays biosecurity [and] the increased cash investment in national biosecurity that would be required of the industry through implementation of GIA'. Until discussions on GIA ensued in 2009, there was general acknowledgment that exotic disease surveillance and response was largely a government function, though implicit in that acknowledgement was that the livestock industries were obliged to use best biosecurity practices, educate farmers about exotic diseases, and promptly report any suspicious diseases to MPI. However, GIA has made it very clear that industry will be required to share some proportion of the funding burden for surveillance and response and therefor the quality and frequency of strategic communications about biosecurity with MPI, and indeed within the industry itself, need to be enhanced.

'Strategic responses' follows on from each Benefit in the ILM diagram. The discussions that occurred during development of the ILM led to a number of potential strategies that might help in achieving a solution for each problem. The strategies identified as being most influential are listed on the ILM diagram along with the relative investment emphasis (i.e. resources) for each. These first three stages of ILM development (identification of Problems, Benefits, and Strategic Responses) are strategic in nature and were developed through various types of facilitated discussion, supported by both qualitative and quantitative evidence. The final stage of ILM development is identification of 'Solutions'. Solutions will almost always require some sort of organisational or procedural 'Change' and some will also require further investment in either human or physical 'Assets'. Discussion around Solutions tends to

be tactical rather than strategic in nature, and tends to be much more straightforward and easy to complete than other components of the ILM process. Done well, ILM leads to a comprehensive, yet easy-to-understand roadmap that clearly prioritizes areas for investment their expected benefits.

Benefit management planning

During the first facilitated discussion, key performance indicators (KPI) were developed for each of the benefits Figure 19 on Page 249. These KPIs were then operationalized during the second facilitated discussions among the NZ Pork Board members and technical staff, and are presented in more detail as part of the Benefit Management Plan (BMP) shown in Figure 20 on Page 250.

As noted previously, the Victoria Management Standard has been designed to focus investment decision-making on the expected benefits of a solution to a problem, rather than simply evaluating a choice of solutions based on their technical merits. The ILM provides a strategic framework upon which this process can be undertaken. However, once the ILM has been created and a series of strategic solutions identified, a process is also required to assist an organisation in achieving those solutions. Under the Standard, this process is referred to as a Benefit Management Plan (BMP).

Similar to an ILM, a BMP is read from left to right with the 'Benefits' previously identified in the ILM providing the initial focus for the diagram. Key performance indicators tied to achievement of benefits are identified and the importance of each is assigned a relative weighting (as defined by the NZ Pork Board). Importantly and as a principal point of difference between the ILM/BMP approach and other investment frameworks, these KPIs are not established to measure performance against solutions, but are established to measure performance against expected benefits. This has the effect of ensuring that the solutions being pursued actually help to achieve the high-level benefits that are desired. An appropriately designed KPI should be: Meaningful (is it a reasonable indicator that the benefit has been delivered), attributable (would this outcome occur without the investment succeeding), and measurable (is there an existing baseline and is it cost-effective to measure progress against this this baseline).[29] Seven KPIs to measure progress towards the desired benefits of an investment in biosecurity were identified by NZ Pork and are shown in Figure 20 on Page 250. Two of the seven are available for reporting as part of existing information systems (DOMESTIC

[29] http://www.dtf.vic.gov.au/CA25713E0002EF43/pages/investment-management-support-in-adopting-the-practices-general-terms-used#KPI, accessed December 26, 2012.

CONSUMPTION, NUMBER OF PREMISES) while five will need to be developed as part of exotic disease surveillance activities (SURVEILLANCE CONFIDENCE, TIME TO CONFIRMATION, CONFIRMATION RATE) or a communication strategy (STAKEHOLDER ENGAGEMENT, and MPI ENGAGEMENT).

Exotic disease surveillance strategy

On the ILM described above and shown in Figure 19 on Page 249, the strategic intervention of most significance was 'Improve surveillance of exotic diseases of pigs'; development of solutions to implement that strategic intervention are described below. The successfulness of the strategy will be monitored using KPIs devised during the ILM process (Figure 20, Page 250).

With regard to an exotic disease incursion into the New Zealand pig industry, the most likely routes of introduction and subsequent spread were identified: Imported pig semen, waste food feeding, and horizontal introduction into the industry via an infected non-pig species. New Zealand currently permits importation of fresh (Australia and New Caledonia) and frozen (Australia, New Caledonia, Canada, the United States, New Caledonia, and Norway) pig semen. However, new IHS are currently under development which would permit importation of fresh semen from Australia, the United States, Canada, the European Union, and Norway. While any person is able to import under these standards, only a limited number of well managed commercial genetic supplier farms actually take advantage of this opportunity. This scenario, coupled with a reporting system that is already in existence and that tracks import activities, creates an intuitively logical activity around which risk-based surveillance might be initiated. Import of live commercial pigs is not currently permitted in New Zealand which effectively minimizes the risk of exotic disease introduction as a result of this activity. Waste food feeding is permitted and widely practised in New Zealand in the non-commercial sector of the industry (Pearson et al 2009). While the practice is regulated and requires that any waste food containing or coming into contact with untreated meat must be cooked at 100^{o}C for 60 minutes, it is believed that compliance with this regulation is poor and enforcement very difficult to achieve (Anonymous 2008; Pearson et al 2009). In fact, as neither licensing nor inspection of waste food feeders (or waste food generators/suppliers) is required, investigation and compliance actions only occur when someone reports an illegal behaviour to MPI compliance officials. While by-product feeding (feeding of waste food not subject to heat treatment described above) is common-place in the commercial industry, only two commercial farms are

known to feed waste food and both have sophisticated supply lines, logistics, and cooking procedures in place to effectively manage the risk.[30] Therefore, the risk of disease incursion as a result of waste food feeding resides primarily in the non-commercial industry but with some likelihood that a disease incursion into the non-commercial industry will be subsequently transmitted into the commercial industry. The likelihood of this occurring has been studied previously through a survey designed to elucidate the habits and behaviours of both commercial and non-commercial pig producers (Pearson et al 2009; Neumann et al 2012) with particular regard to the likelihood of transmitting PRRS virus between the two industry sectors (Neumann et al 2007b). While the estimated frequency of contacts between pigs (and farms) in the two sectors was found to be relatively infrequent in the study, the substantial number of non-commercial pig holdings (estimated between 7,000 and 20,000 sites) magnifies the effect of any risky behaviours that does occur in that sector.

Horizontal introduction of an exotic disease into the pig industry as a result of a transmission event from an infected non-pig species is possible. Foot and mouth disease and influenza are of particular concern in this light though the list of possible, but less likely diseases is long (exotic or multi-drug resistant *Salmonellae* species, arboviruses, exotic *Leptospira* species, haemorrhagic septicaemia, and others). Aside from implementing comprehensive on-farm biosecurity programmes designed to exclude contact with these types of diseases (Ramirez and Zaabel 2012), on-farm surveillance is critical in assisting with early detection of a disease incursion. On-farm surveillance may include both passive and active components and be designed around either random or targeted (risk-based) sampling strategies. Components of a disease surveillance strategy for the New Zealand commercial pig industry are described below.

Active, random surveillance components

Rather than periodically establishing proof-of-freedom from certain exotic diseases that would support pork export opportunities, the strategic planning exercise undertaken by NZ Pork identified that ensuring the 'industry remains free of exotic disease' (or what might be referred to as early detection of an incursion) was of more interest to the organisation. One activity that was investigated as a means of achieving this was collection of diagnostic samples at commercial abattoirs. While abattoir sampling is inherently biased by virtue of the fact that only healthy animals are being delivered to

[30] Clement, F. Personal communication, December 23, 2012.

an abattoir, it has the advantages of occurring frequently (New Zealand abattoirs are operating 5-6 days per week every week of the year), is based on slaughtering pigs of known farm origin (origin and numbers to be delivered are known 7-10 days ahead of delivery), and provides a geographically representative sample of the entire industry (five abattoirs process greater than 95% of the commercial pigs i.e. nearly all pigs from all commercial farm eventually end up at one of these five abattoirs).

The cost and effectiveness of sampling fewer pigs (but sampling them more frequently) as compared to annual proof-of-freedom testing was modelled. Two models were developed: The first established the number of samples required and cost of testing for an annual proof-of-freedom testing programme, and the second established the same information for a bi-monthly testing programme Table 24 on Page 244. The annual testing programme was designed to detect a positive pig or herd with 99% confidence if the between-herd prevalence was greater than or equal to 1% and the within-herd prevalence was greater than or equal to 15% (a '99/1/15' sampling protocol); this testing programme required 27 pigs from each of 95 herds to be tested (n = 2,565) each year. The bi-monthly testing programme required a proof-of-freedom test be conducted at the beginning of the first year to unequivocally establish the population was free of the disease. Once the proof-of-freedom was established with known statistical certainty, testing smaller numbers of samples at frequent (bi-monthly) intervals permitted a continued high level of confidence in disease freedom due to the Bayesian-like influence provided by knowledge of the population's disease status from the prior month. In the first month of sampling, three samples were randomly collected from each of 31 randomly selected herds providing an 80/5/40 point-in-time confidence. Over a three-year cycle, the sampling intensity was increased such that the final bi-monthly sampling required that nine pigs be randomly selected from each of 58 randomly selected herds to establish a 95/3/30 confidence level. Over the three-year period, the annual proof-of-freedom sampling programme cost $146,616 while the bi-monthly programme cost $125,251. A three-year cycle was chosen based on breeding herds having an annual turnover rate of approximately 35% suggesting herds would be completely replaced about every three years.

Using a similar approach, abattoir-based sampling of chopper sows was also modelled and the results shown in Table 25 on Page 245. Over the three-year period that was modelled, the annual proof-of-freedom sampling programme cost $131,792 while the bi-monthly programme cost $117,105.

The above sampling could be implemented using either serum or meat juice cytosols (Molina et al 2008), as protocols have been developed for both types of samples with the IDEXX test.

Active, risk-based surveillance components

Given the limited numbers of industry players that are involved in import of semen and further distribution of genetic material (boars, replacement gilts, and semen) to the rest of the New Zealand industry, they provide a logical surveillance node at which active, risk-based sampling could occur. Routine testing of animals at these sites would provide some further assurance (beyond the required export testing of the source herd) that the risk material from overseas has not resulted in any infection in the importing herd, and that if an infection did occur it would be detected before substantial downstream spread to domestic genetic customer herds occurs.

Table 26 on Page 246 describes the costs associated with monthly testing of the commercial genetic infrastructure of the New Zealand pig industry. The programme is based on achieving a 95% confidence in detecting a positive pig if the disease prevalence is greater than or equal to 5% and is expected to cost $48,600 per year.

The above modelling is based on use of individual animal serum testing for antibodies using the PRRS ELISA described above. However, novel work is occurring in the United States based on collection of oral fluids (rather than blood) for antibody testing and which provides an important opportunity to re-evaluate how surveillance of genetic suppliers could be conducted in New Zealand (Kittawornrat et al 2010; Kittawornrat et al 2012a; Kittawornrat et al 2012b). Oral fluid testing has the potential to result in a programme that is easier, less expensive, and equally effective to one based on blood testing. The basic technique for collection of oral fluids involves hanging cotton ropes in pens of pigs for 10-30 minutes, which allows time for a number of the pigs in that pen to chew on the absorbent rope and deposit antibody-containing oral fluids on the rope. At the end of the collection period, the oral-fluids are expressed into a sample collection bag and sent to a laboratory for analysis using a modified ELISA protocol that has already been approved internationally.[31] The technique has the advantages of automatically pooling a number of animals into a single sample thereby improving testing sensitivity, and lowering cost as the sample can be collected passively by the

[31] 'Testing swine oral fluids is a convenient and cost-effective method for PRRS monitoring and surveillance in commercial herds'. Can be viewed at http://www.idexx.com/pubwebresources/pdf/en_us/livestock-poultry/prrs-of-ab-test-info-brochure.pdf, accessed December 26, 2012.

farmer rather than by an external technician or veterinarian. Work on oral fluids continues in order to develop sampling algorithms that can reliably determine the disease status of a pen, or population of pigs.

Passive, systematic surveillance components

PigCheck, the systematic programme of evaluating carcasses at abattoirs for the presence of disease lesions has been described previously (Neumann et al Submitted (2012)). As the data is already being collected in a systematic manner (all pigs slaughtered in commercial abattoirs), using inspectors trained to follow established case definitions for 22 lesions, and stores data in an online-accessible database it would be a straightforward task to aggregate this data on a weekly (and monthly, yearly) basis for analysis that could identify aberrations in the occurrence of any of the lesions. The data is well-suited to generation of easily understood graphical output and more in depth analysis including time-series and statistical process control could be easily implemented.

At the moment, PigCheck is funded by individual producers at the rate of approximately $0.17 per pig or around $127,000 annually across the industry. To undertake aggregate analysis of this data, permission may need to be granted by each individual farmer for use of their data. This may not be difficult to achieve as individual farm identification could be removed from the data as it would not be necessary for generalized reporting purposes. However, in the event an aberration is detected it would be necessary to recover farm identification data so that appropriate follow-up could occur. The estimated overhead costs of developing and maintaining an aggregated reporting structure for the PigCheck data is around $25,000 per year not including the cost of data collection which is currently being paid by individual farmers participating in the PigCheck programme Table 27 on Page 247.

Passive, risk-based surveillance component

Routine diagnostic laboratory submissions provide a useful means of generating surveillance samples specifically from sick pigs. As described above, MPI already has arrangements in place with the two major private diagnostic laboratory companies in New Zealand to share limited information from unusual cases that are submitted to one of their laboratories. However, for this system to be useful the farmer or veterinarian has to be sufficiently motivated to initiate a submission to the laboratory. At the moment, only one to two pig cases (excluding serology-only submissions) are typically being

submitted to the laboratories each month.[32] As an incentive to increase the case load and the breadth of testing completed on each case, a subsidy programme was investigated as a means of directly lowering the cost of diagnostic laboratory services to the farmer. Simple stochastic modelling was done using simulation software (@RISK 5.7; Palisade Asia-Pacific Pty Limited, Milsons Point, NSW, Australia) to estimate the annual cost of a subsidy programme to the industry based on increasing the typical monthly case load by one to five cases per month (=RiskDiscrete({1,2,3,4,5},{1,1,1,1,1}), providing approximately $200 per case to offset the cost of delivering live pigs to the laboratory (instead of sending tissue samples by courier), providing approximately $200 per case to cover additional expenses related to a multi-pig submission, and providing approximately $100 to cover additional testing that would not normally be undertaken as part of a routine diagnostic workup. This subsidy was added to the base cost (=RiskPert(75,325,500) of a typical diagnostic submission. Under this scenario, the average total cost of the subsidy programme per case was $782 yielding an average total annual cost of approximately $22,000 (ranging from $13,000 to $32,000 per year) to the industry.

Surveillance components considered and rejected

In developing a biosecurity strategy for NZ Pork, several approaches were suggested but later rejected as feasible components of a surveillance programme. Given the industry's widespread adoption of a single computerized production record system, it seemed that aggregation and analysis of the records from all farms would be useful as part of a syndromic surveillance system. This is technically feasible within the software system but discussions amongst the NZ Pork Board members and staff suggested there would likely be reluctance by farmers to share their performance information. Confidentiality issues could be managed over time but the core issue seemed to be reluctance by farmers to take on one more office-related task when the personal benefit of that task was not going to be immediately apparent. Realistically, an exotic disease incursion is a rare event and there was a feeling that individual farmers would have to invest in a weekly or monthly activity for which they may rarely, if ever, receive the benefit. Discussions are on-going with the software developer to explore the possibility of adding a one-click synchronization function to the software that would upload the data most useful for syndromic surveillance to a server for centralized analysis. This

[32] Campbell, R. New Zealand Veterinary Pathology, personal communication, August 15, 2012.

process could strip the data of farm identification fields and minimize the time and effort required by the farmer to share the information.

As discussed previously, use of computerized record systems for managing post-weaning pigs is not widespread nor is the data recorded in a standardized manner among farms. However, this population of pigs does represent approximately 90% of a point-in-time inventory of commercial pigs in the country and their importance to a surveillance programmed should not be underestimated. As a first step in utilizing performance data from growing pigs, it might be useful simply to encourage farmers to report total number of post-weaning mortalities on a weekly or monthly basis via fax, email, or a simple web form for aggregated analysis.

Monthly blood sample collection from a random selection of commercial farms to be used for serologic antibody testing would be a very useful adjunct to a national surveillance programme. However, there was again a feeling that farmers would be reluctant to take on this additional responsibility and cost as the benefit of the activity would only be realised in the event of a disease outbreak. However, if the process could be simplified, perhaps through a method such as collection of oral fluids as described earlier, it would be feasible to incorporate into a surveillance programme.

Waste food feeding is a common practice in the non-commercial pig industry and given the proposed relaxation of border standards for imported fresh pork, the risk of an exotic disease being introduced into the non-commercial industry is increasing; this in turn places the commercial industry at increased risk of an exotic disease incursion. Non-commercial pig owners are not required to be registered with NZ Pork, not required to be registered in the national farm database system, and are not required to identify their pigs. Therefore the number and location of non-commercial pigs are not well known. This fact substantially complicates surveillance activities in the non-commercial industry and as such leaves an important risk unmonitored. As NZ Pork has no means or authority to coordinate surveillance activities in the non-commercial industry, managing this population of pig owners must remain a function of government.

Discussion and conclusions

Surveillance for exotic diseases in the New Zealand pig industry is currently under-developed and presents an unacceptable risk to the health status and future sustainability of the industry. While exotic disease surveillance has traditionally been a function of government, New Zealand and other country governments are actively scaling back their investment in disease preparedness and response on the basis that those receiving

the most direct benefit of the investment (farmers) should be responsible for funding disease management programmes. The process of formally understanding the benefits of these programmes and assigning their costs is currently under way in New Zealand through implementation of GIA.

NZ Pork recently completed a strategic planning exercise to explore how the industry might best invest in biosecurity using a benefits-focussed tool called ILM. Through this process it became clear that establishment of a national surveillance programme would yield substantial benefits related to a number of recognized biosecurity problems. Various components of a surveillance programme including both active and passive mechanisms were assessed in terms of their cost and feasibility. A combination of abattoir-based sampling ($125, 251 for growing pigs and $117,105 for chopper sows per year), on-farm surveillance of genetic suppliers ($48,600 per year), analysis of PigCheck data ($25,000 per year), and establishment of a diagnostic laboratory subsidy ($22,000 per year) were recommended as the key components of a surveillance system that could be established quickly and at a reasonable cost ($337,956 per year or approximately $0.50 per pig sold). This investment includes funding for a full-time biosecurity and surveillance manager at NZ Pork. It appears reasonable that the cost of this surveillance programme should be shared by government, the pig industry, and allied industries (abattoirs, pork distribution, feed and veterinary suppliers, etc.) as all either have an obligation to participate or will receive the benefit if a disease incursion is detected rapidly.

The non-commercial pig industry in New Zealand is substantial and behaviours in the industry such as waste food feeding place it at risk of becoming infected with an exotic disease such as PRRS, FMD, or classical swine fever. Non-commercial pig owners are not required to be registered on any national animal or farm location databases and therefore a dedicated effort will be required for them to be included in any surveillance activities. This dedicated effort falls well outside the mandate or authority of NZ Pork and will need to be taken on as a government function.

References

***Anderson LA, Black N, Hagerty TJ, Kluge JP, Sundberg P.** Pseudorabies (Aujeszky's Disease) and Its Eradication: A Review of the U.S. Experience (Technical Bulletin Number 1923). *United States Department of Agriculture*, Washington, D.C, USA, 2008

***Anonymous.** Government and livestock industry cost sharing deed in respect of emergency animal disease responses, Variation Number 11/01 –28/06/11. *Commonwealth of Australia*, Kingston, ACT, Australia, 2001

***Anonymous.** The macroeconomic impacts of a foot-and-mouth disease outbreak: an information paper for Department of the Prime Minister and Cabinet. *Reserve Bank of New Zealand*, Wellington, New Zealand, 2003

***Anonymous.** MAF Biosecurity Authority Standard AS 50-008 for the National Centre for Disease Investigation Exotic Disease Response Centre's Surveillance Functions Issue (Version 1). *Ministry of Agriculture and Forestry*, Wellington, New Zealand, 2004

***Anonymous.** Review of the Biosecurity (Meat and Food Waste for Pigs) Regulations 2005. *Ministry of Agriculture and Forestry - Enforcement Group*, Wellington, 2008

***Anonymous.** Government-Industry Agreements. *Ministry of Agriculture and Forestry*, Wellington, New Zealand, 2009a

***Anonymous.** Biosecurity Surveillance Strategy 2020. *Ministry of Agriculture and Forestry*, Wellington, New Zealand, 2009b

***Anonymous.** Annual Report of New Zealand Pork Industry Board. *NZ Pork*, Wellington, New Zealand, 2011

***Anonymous.** Better Business Cases (Overview). *New Zealand Treasury*, Wellington, New Zealand, 2012

Branscum AJ, Johnson WO, Gardner IA. Sample size calculations for disease freedom and prevalence estimation surveys. *Statistics in Medicine* 25, 2658-74, 2006

Cameron AR, Baldock FC. A new probability formula for surveys to substantiate freedom from disease. *Preventive Veterinary Medicine* 34, 1-17, 1998a

Cameron AR, Baldock FC. Two-stage sampling in surveys to substantiate freedom from disease. *Preventive Veterinary Medicine* 34, 19-30, 1998b

Cannon RM, Roe RT. Livestock disease surveys : a field manual for veterinarians, Australian Government Publishing Service, Canberra, 1982

Garner MG, Gleeson LJ, Holyoake PK, Cannon RM, Doughty WJ. A national serological survey to verify Australia's freedom from porcine reproductive and respiratory syndrome. *Australian Veterinary Journal* 75, 596-600, 1997

Hernandez-Jover M, Cogger N, Martin PA, Schembri N, Holyoake PK, Toribio JA. Evaluation of post-farm-gate passive surveillance in swine for the detection of foot and mouth disease in Australia. *Preventive Veterinary Medicine* 100, 171-86, 2011

Johnson WO, Su CL, Gardner IA, Christensen R. Sample size calculations for surveys to substantiate freedom of populations from infectious agents. *Biometrics* 60, 165-71, 2004

Kittawornrat A, Prickett J, Chittick W, Wang C, Engle M, Johnson J, Patnayak D, Schwartz T, Whitney D, Olsen C, Schwartz K, Zimmerman J. Porcine reproductive and respiratory syndrome virus (PRRSV) in serum and oral fluid samples from individual boars: will oral fluid replace serum for PRRSV surveillance? *Virus Research* 154, 170-6, 2010

Kittawornrat A, Prickett J, Wang C, Olsen C, Irwin C, Panyasing Y, Ballagi A, Rice A, Main R, Johnson J, Rademacher C, Hoogland M, Rowland R, Zimmerman J. Detection of Porcine reproductive and respiratory syndrome virus (PRRSV) antibodies in oral fluid specimens using a commercial PRRSV serum antibody enzyme-linked immunosorbent assay. *Journal of veterinary diagnostic investigation : official publication of the American Association of Veterinary Laboratory Diagnosticians, Inc* 24, 262-9, 2012a

Kittawornrat A, Wang C, Anderson G, Ballagi A, Broes A, Carman S, Doolittle K, Galeota J, Johnson J, Lizano S, Nelson E, Patnayak D, Pogranichniy R, Rice A, Scherba G, Zimmerman J. Ring test evaluation of the repeatability and reproducibility of a Porcine reproductive and respiratory syndrome virus oral fluid antibody enzyme-linked immunosorbent assay. *Journal of veterinary diagnostic investigation : official publication of the American Association of Veterinary Laboratory Diagnosticians, Inc* 24, 1057-63, 2012b

Knight J. Advance Australia fair? Anatomy and pathology of an 84-year trade dispute. *Journal of Public Affairs* 5, 112–23, 2005

Larner W. Neoliberalism, Mike Moore, and the WTO. *Environment and Planning A* 41, 1576-93, 2009

Martin PA, Cameron AR, Barfod K, Sergeant ES, Greiner M. Demonstrating freedom from disease using multiple complex data sources 2: case study--classical swine fever in Denmark. *Preventive Veterinary Medicine* 79, 98-115, 2007a

Martin PA, Cameron AR, Greiner M. Demonstrating freedom from disease using multiple complex data sources 1: a new methodology based on scenario trees. *Preventive Veterinary Medicine* 79, 71-97, 2007b

Martin PAJ. Current value of historical and ongoing surveillance for disease freedom: Surveillance for bovine Johne's disease in Western Australia. *Preventive Veterinary Medicine* 84, 291-309, 2008

Molina RM, Chittick W, Nelson EA, Christopher-Hennings J, Rowland RR, Zimmerman JJ. Diagnostic performance of assays for the detection of anti-Porcine reproductive and respiratory syndrome virus antibodies in serum and muscle transudate ("meat juice") based on samples collected under experimental conditions. *Journal of Veterinary Diagnostic Investigation* 20, 735-43, 2008

Motha MXJ, Stark KK, Thompson J. New Zealand is free from PRRS , TGE and PRCV. *Surveillance* 24, 10-1, 1997

Neumann E, Simpson S, Wagner J, Karaconji B. Longitudinal field study of the effect of a commercial porcine circovirus type 2 vaccine on postweaning mortality in New Zealand farms. *Journal of Swine Health and Production* 17, 204-9, 2009

Neumann EJ, Dobbinson SS, Welch EB, Morris RS. Descriptive summary of an outbreak of porcine post-weaning multisystemic wasting syndrome (PMWS) in New Zealand. *New Zealand Veterinary Journal* 55, 346-52, 2007a

Neumann EJ, Morris RS, Sujau M. Analysis of the risk of introduction and spread of porcine reproductive and respiratory syndrome virus through importation of raw pigmeat into New Zealand. *New Zealand Veterinary Journal* 55, 326-36, 2007b

Neumann EJ, Morris RS. Re: Re: Analysis of the risk of introduction and spread of porcine reproductive and respiratory syndrome virus through importation of raw pigmeat into New Zealand. *New Zealand Veterinary Journal* 56, 149-50, 2008

Neumann EJ, Pearson AB, Sanson RL, Nicoll KJ, Clement FL. The frequency and distance of movements of pigs and semen between commercial and non-commercial piggeries in New Zealand. *New Zealand Veterinary Journal*, 1-10, 2012

Neumann EJ, Hall WF, Stevenson MA, Morris RS, Ling Min Than J. Descriptive and temporal analysis of post-mortem lesions recorded in New Zealand slaughter pigs from 1999-2010. *New Zealand Veterinary Journal*, Submitted (2012)

O'Neil BD. Re: Analysis of the risk of introduction and spread of porcine reproductive and respiratory syndrome virus through importation of raw pigmeat into New Zealand. *New Zealand Veterinary Journal* 56, 48-, 2008

***Oughton D, Evans J, Gough J.** Independent Review Panel Report on the Import Health Standard for the Importation into New Zealand of Specified Bee Products from Australia. *Ministry of Agriculture and Forestry*, Wellington, New Zealand, 2009

***Pearson A, Neumann EJ, Sanson RL, Nicol K, Clement F.** Pig Movements Transmission of Exotic Diseases - Report Number 07 10 475. *Ministry of Agriculture and Forestry*, Wellington, New Zealand, 2009

***Ramirez A, Zaabel P.** Swine Biological Risk Management. *Iowa State University Center for Food Security and Public Health*, Ames, Iowa, United States, 2012

Stone M, Kittelberger R. Serological survey for PRRS during a response to PMWS. *Surveillance* 31, 15-7, 2004

***Stone M.** The potential for exotic disease syndromic surveillance within veterinary laboratory submissions data. *In Proceedings of: 'The Food Safety, Animal Welfare & Biosecurity, Epidemiology & Animal Health Management, and Industry branches of the NZVA'*. Palmerston North, New Zealand Pp 91-102. (VetLearn Foundation), 2007

Ziller M, Selhorst T, Teuffert J, Kramer M, Schluter H. Analysis of sampling strategies to substantiate freedom from disease in large areas. *Preventive Veterinary Medicine* 52, 333-43, 2002

Tables

Table 24. Cost and sampling strategies for annual proof-of-freedom surveillance (99% confidence of de herds were positive and 15% of pigs were positive) compared to bi-monthly sampling with lower expec positive herds or pigs. Sampling strategy based on use of IDEXX PRRS HerdCheck ELISA (Sensitivity herds of growing pigs in the population, and 1,300 grower pigs per herd.

		2011	Feb-2012	Apr-2012	Jun-2012	Aug-2012	Oct-2012	Dec-2012	Feb-2013	Apr-2013	Jun-2013	Aug-2013	Oct-2013	Dec-2013	Feb-2014	Ap
Criteria		Month 00	Month 02	Month 04	Month 06	Month 08	Month 10	Month 12	Month 14	Month 16	Month 18	Month 20	Month 22	Month 24	Month 26	Mo
Number herds		95	31	31	31	33	33	33	39	39	39	43	43	43	51	
Per herd		27	3	3	3	4	4	4	5	5	5	7	7	7	7	
Total		2565	93	93	93	132	132	132	195	195	195	301	301	301	357	
Cumul		2565	2658	2751	2844	2976	3108	3240	3435	3630	3825	4126	4427	4728	5085	
Testing level (conf/between_P/within_P)		99/1/15	80/5/40	80/5/40	80/5/40	85/5/40	85/5/40	85/5/40	85/4/30	85/4/30	85/4/30	90/4/30	90/4/30	90/4/30	90/3/30	9
Reference (annual testing)		2565						2565						2565		
Expense	per unit	2011	Feb-2012	Apr-2012	Jun-2012	Aug-2012	Oct-2012	Dec-2012	Feb-2013	Apr-2013	Jun-2013	Aug-2013	Oct-2013	Dec-2013	Feb-2014	Ap
Sampling materials	0.50	1,282.50	46.50	46.50	46.50	66.00	66.00	66.00	97.50	97.50	97.50	150.50	150.50	150.50	178.50	
Collection labour	3.00	7,695.00	279.00	279.00	279.00	396.00	396.00	396.00	585.00	585.00	585.00	903.00	903.00	903.00	1,071.00	1
Local handling and shipping (total 5 plants)	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	
Int'l ship to Iowa State Univ	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	
IDEXX ELISA lab charge	6.00	15,390.00	558.00	558.00	558.00	792.00	792.00	792.00	1,170.00	1,170.00	1,170.00	1,806.00	1,806.00	1,806.00	2,142.00	2
FP retest	12.00	624.00	24.00	24.00	24.00	36.00	36.00	36.00	48.00	48.00	48.00	84.00	84.00	84.00	96.00	
Surveillance manager (0.2 FTE)	74,750.00		2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2
Total		25,441.50	3,849.17	3,849.17	3,849.17	4,231.67	4,231.67	4,231.67	4,842.17	4,842.17	4,842.17	5,885.17	5,885.17	5,885.17	6,429.17	6
Yearly totals		Startup						End of Y1						End of Y2		
Reference (annual testing)		25,441.50						40,391.50						40,391.50		
Reference (monthly testing)		25,441.50						24,242.50						32,182.00		

Table 25. Cost and sampling strategies for annual proof-of-freedom surveillance (99% confidence of de herds were positive and 15% of sows were positive) compared to bi-monthly sampling with lower expe positive herds or sows. Sampling strategy based on use of IDEXX PRRS HerdCheck ELISA (Sensitivit breeding herds in the population, and 170 breeding sows per herd.

		2011	Feb-2012	Apr-2012	Jun-2012	Aug-2012	Oct-2012	Dec-2012	Feb-2013	Apr-2013	Jun-2013	Aug-2013	Oct-2013	Dec-2013	Feb-2014	A
Criteria		**Month 00**	**Month 02**	**Month 04**	**Month 06**	**Month 08**	**Month 10**	**Month 12**	**Month 14**	**Month 16**	**Month 18**	**Month 20**	**Month 22**	**Month 24**	**Month 26**	**Mo**
Number herds		95	31	31	31	33	33	33	39	39	39	43	43	43	51	
Per herd		23	3	3	3	4	4	4	5	5	5	6	6	6	6	
Total		2185	93	93	93	132	132	132	195	195	195	258	258	258	306	
Cumul		2185	2278	2371	2464	2596	2728	2860	3055	3250	3445	3703	3961	4219	4525	
Testing level (conf/between_P/within_P)		**99/1/15**	**80/5/40**	**80/5/40**	**80/5/40**	**85/5/40**	**85/5/40**	**85/5/40**	**85/4/30**	**85/4/30**	**85/4/30**	**90/4/30**	**90/4/30**	**90/4/30**	**90/3/30**	**9**
Reference (annual testing)		**2565**						**2565**						**2565**		
Expense	**per unit**	**2011**	**Feb-2012**	**Apr-2012**	**Jun-2012**	**Aug-2012**	**Oct-2012**	**Dec-2012**	**Feb-2013**	**Apr-2013**	**Jun-2013**	**Aug-2013**	**Oct-2013**	**Dec-2013**	**Feb-2014**	**A**
Sampling materials	**0.50**	1,092.50	46.50	46.50	46.50	66.00	66.00	66.00	97.50	97.50	97.50	129.00	129.00	129.00	153.00	
Collection labour	**3.00**	6,555.00	279.00	279.00	279.00	396.00	396.00	396.00	585.00	585.00	585.00	774.00	774.00	774.00	918.00	
Local handling and shipping (total 5 plants)	**200.00**	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	
Int'l ship to Iowa State Univ	**250.00**	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	250.00	
IDEXX ELISA lab charge	**6.00**	13,110.00	558.00	558.00	558.00	792.00	792.00	792.00	1,170.00	1,170.00	1,170.00	1,548.00	1,548.00	1,548.00	1,836.00	1
FP retest	**12.00**	528.00	24.00	24.00	24.00	36.00	36.00	36.00	48.00	48.00	48.00	72.00	72.00	72.00	84.00	
Surveillance manager (0.2 FTE)	**74,750.00**		2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2
Total		**21,735.50**	**3,849.17**	**3,849.17**	**3,849.17**	**4,231.67**	**4,231.67**	**4,231.67**	**4,842.17**	**4,842.17**	**4,842.17**	**5,464.67**	**5,464.67**	**5,464.67**	**5,932.67**	**5**
Yearly totals		**Startup**						**End of Y1**						**End of Y2**		
Reference (annual testing)		**21,735.50**						**36,685.50**						**36,685.50**		
Reference (monthly testing)		**21,735.50**						**24,242.50**						**30,920.50**		

Table 26. Sample requirements and estimated costs to establish a monthly surveillance programme of s suppliers in the New Zealand pig industry. Sampling requirements based on achieved 95% confidence within herd prevalence of infection.

Inventory	Monthly samples req'd per herd	Avg cost per sample	Num herds	Samples req'd month	Samples req'd year	Total cost per year
<30 animals	15	$15.00	2	30	360	$5,400.00
31-1000 animals	30	$15.00	4	120	1440	$21,600.00
>1000 animals	60	$15.00	2	120	1440	$21,600.00
					TOTAL COST	**$48,600.00**

Table 27. Overhead costs for monthly aggregated reporting of PigCheck abattoir lesion data. Estimate
data collection which is currently being paid by individual farmers participating in the PigCheck progr

Expense	per unit	2011	Feb-2012	Apr-2012	Jun-2012	Aug-2012	Oct-2012	Dec-2012	Feb-2013	Apr-2013	Jun-2013	Aug-2013	Oct-2013	De
SPC software	2,500.00	2,500.00												
Database connectivity MU-AsureQuality	5,000.00	5,000.00												
Data cleanup - AgriBase/FarmsOnline	2,500.00	2,500.00												
Develop reporting structure	5,000.00	5,000.00						5,000.00						
Road show	5,000.00	5,000.00						5,000.00						5,(
Surveillance manager (0.2 FTE)	74,750.00		2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,491.67	2,4
Signal follow-up (phone)	10.00		400.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	400.00	
Signal follow-up (farm/abattoir visit)	250.00		500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	500.00	
Total		20,000.00	3,391.67	3,391.67	3,391.67	3,391.67	3,391.67	13,391.67	3,391.67	3,391.67	3,391.67	3,391.67	3,391.67	8,3
Yearly totals		Startup						End of Y1						End
		20,000.00						30,350.00						25,3

Figures

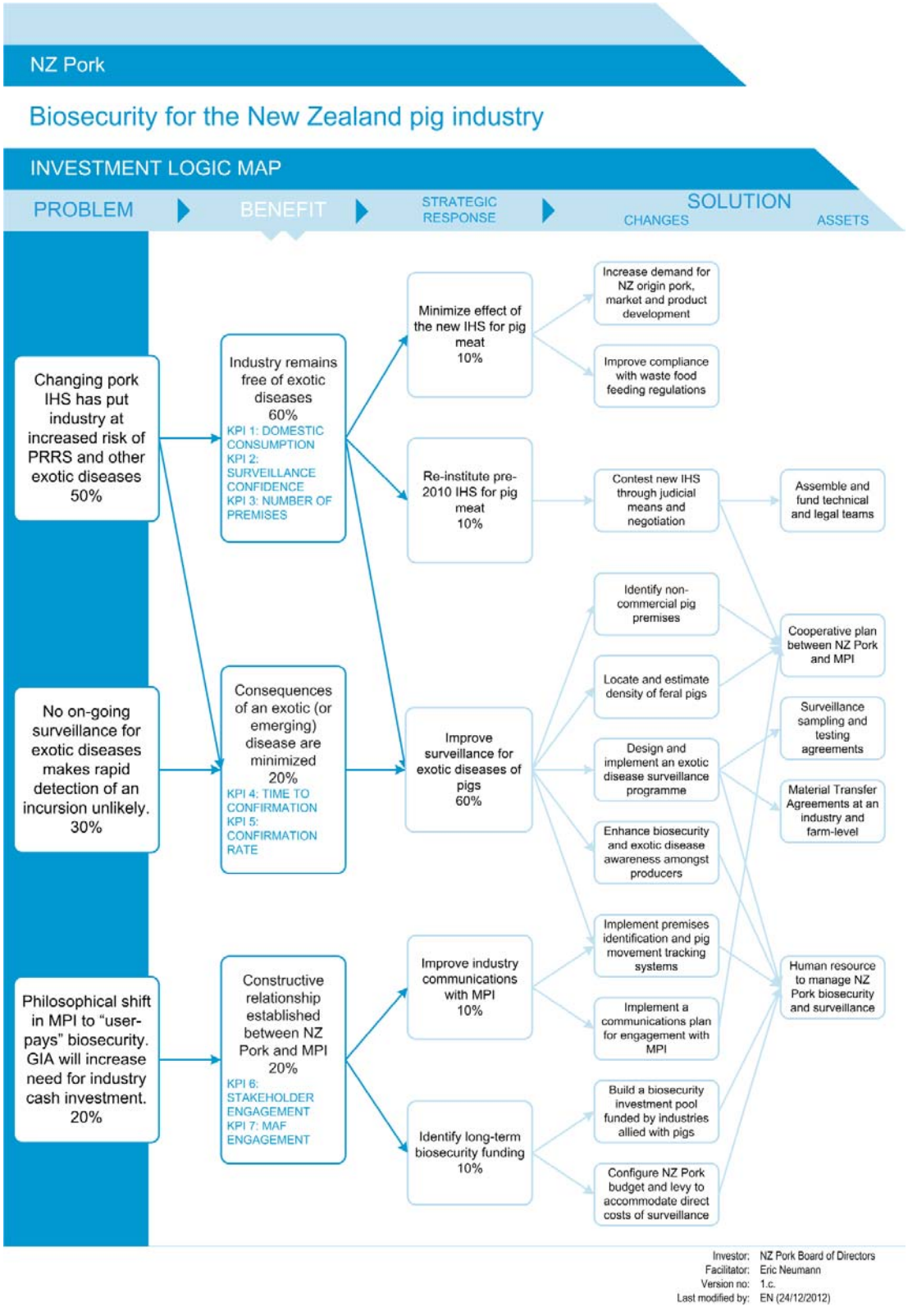


Figure 19. Investment Logic Map describing the benefits to be achieved through an investment in biosecurity and disease surveillance by NZ Pork.

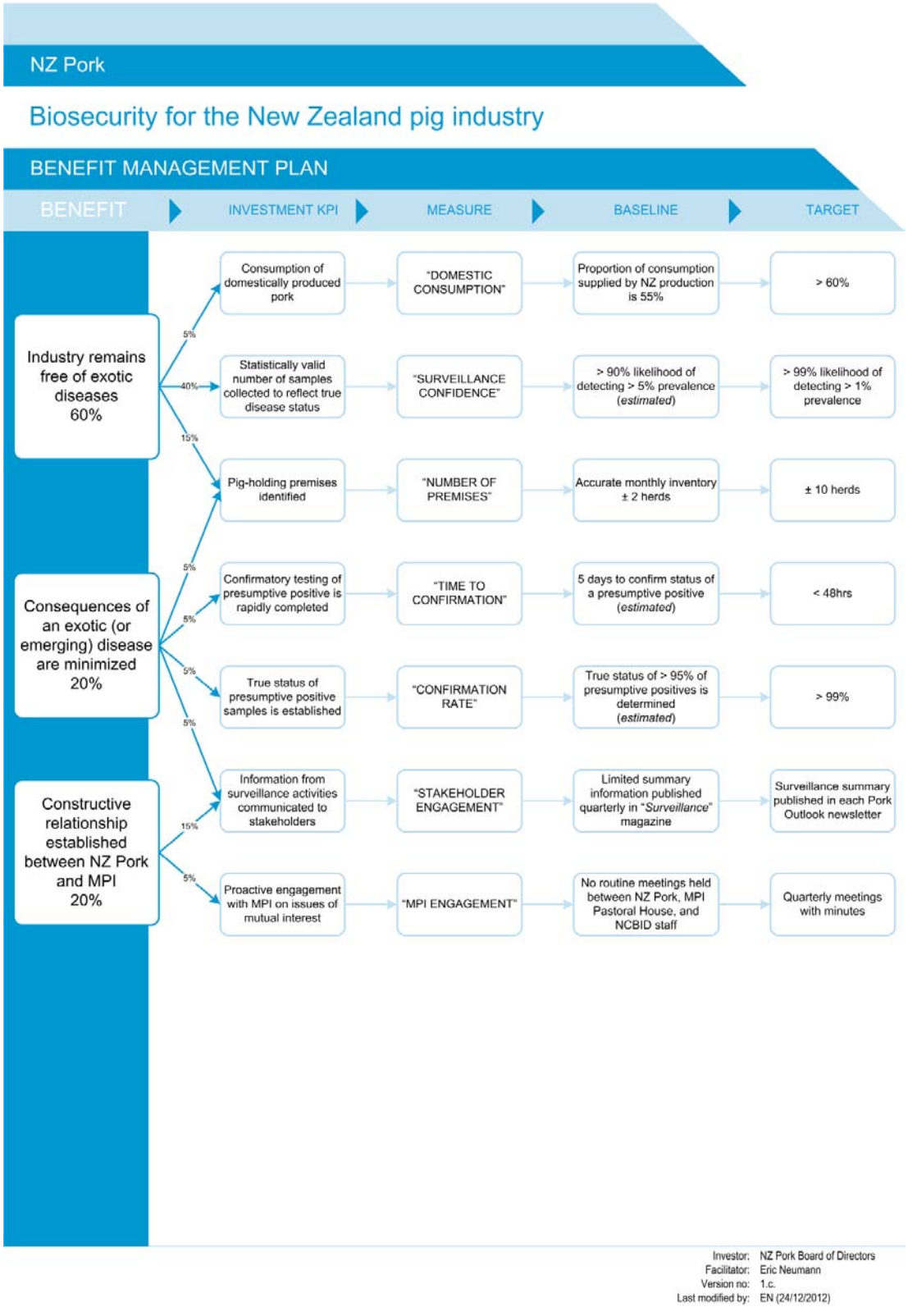


Figure 20. Benefit Management Plan describing the key performance indicators that will be established and monitored to achieve the desired benefits of solving problems previously identified by NZ Pork through an Investment Logic Mapping exercise.

General discussion

This thesis explores several aspects of the New Zealand pig industry that are important to development of a robust national biosecurity and surveillance programme. To maintain its current freedom from many of the significant pig diseases common to much of the world, a biosecurity programme must be established that monitors the effectiveness of MPI managed border security systems and monitors the pig industry post-border to quickly identify any incursion that escapes existing border controls, or a pathogen that emerges within New Zealand. A significant complication to managing the health of the commercial industry is the existence of a large and minimally regulated non-commercial pig industry. This non-commercial industry has substantial geographic overlap with the commercial industry though the exact numbers of premises (and locations) are unknown as these pig holdings fall outside obligatory national livestock management schemes such as FarmsOnline,[33] the AgriBase farms database,[34] and NZ Pork. Because they operate outside of these national registries, providing them with educational materials and training on biosecurity, incorporating them into national disease surveillance programmes, and managing them in the face of an exotic disease outbreak will be a difficult process at best.

The non-commercial sector of the New Zealand pig industry has not been extensively studied. However, several features of the sector have been reported which suggest that it may be pose a special risk for exotic disease introduction and transmission to the commercial sector. First, the sector appears to practise waste food feeding, with estimates suggesting that perhaps 35 to 98% of non-commercial farms practiced some form of waste food feeding (Stone 2005; Pearson et al 2009). The activity is common enough that MPI undertook a formal audit of the effectiveness of the compliance activity around the waste food feeding regulation and noted that 'the Biosecurity (Meat and Food Waste for Pigs) Regulations 2005 do not enable the Enforcement Group to effectively monitor compliance with the regulations or deter offenders' (Anonymous 2008). The New Zealand commercial pig industry sponsored research that attempted to quantify the amount of waste food that was being fed by non-commercial farms and found (Anonymous 2011):

[33] http://farmsonline.maf.govt.nz/, accessed December 31, 2012.
[34] http://www.asurequality.com/capturing-information-technology-across-the-supply-chain/agribase-database-for-nz-rural-properties.cfm, accessed December 31, 2012.

- Most non-commercial farms that collect commercial food waste pick it up at least one time per week, with almost two-fifths of larger pig owners picking up at least 50 twenty litre buckets of commercial food waste a week.
- This same group of larger pig owners were more likely than the smaller pig owners to have arrangements with multiple sources to provide the waste food.
- More than a fifth of non-commercial pig owners, who maintained regular supply relationships with a source of commercial food waste, also picked up food scraps on an ad-hoc basis from other commercial sources.

Second, non-commercial piggeries are known to interact with other livestock owners more frequently than those in the commercial sector as evidenced by more frequent use of saleyards and more reliance on trade in store pigs (Pearson et al 2009). Disease investigations undertaken in connection with suspected and confirmed disease incursions (Aujeszky's disease, marine Brucella infection, post-weaning multisystemic disease in North and South Islands separately) have also demonstrated that waste food and other feeds, implements and other potential fomites are exchanged freely among the farms investigated. Third, farms in the non-commercial sector tend to adopt behaviours that suggest poor overall awareness of biosecurity principles such as feeding of raw/ untreated milk to pigs (also potentially containing antibiotic residues), actively participate in home butchering (with unknown management procedures for offal and carcass remnants, include feeding back to pigs), and own multiple species of livestock which typically are commingled or co-grazed (Pearson et al 2009).

A comprehensive review of pig industry biosecurity and disease transmission has been presented in Chapter 1. A thorough understanding of these topics is necessary in order to build and implement a biosecurity system for the New Zealand industry. The concept of disease ecology is introduced as a means of thinking more holistically not only about disease transmission but also about surveillance. While it is generally accepted that no 'one size fits all' surveillance programme exists that would suit the myriad pathogens of concern to the industry, it seems that pathogens can be logically grouped by epidemiological features that would assist in development of national readiness, response, and eradication programmes. By focussing on mechanisms of disease persistence as a useful epidemiologic feature to establish these groupings, five groups of pathogens have been proposed in Chapter 1: Vector-borne, short-cycle, long-cycle, resistant, and commensal organisms. Recently, Desrosiers explored a similar approach to categorizing pig diseases and utilized PRRS virus, *M. hyopneumoniae*, *Sarcoptes*

*scabe*i, and others as examples of disease 'types' whose successful control or eradication could be explained by their epidemiological characteristics (Desrosiers 2011). An exotic disease surveillance programme for the New Zealand pig industry is presented in Chapter 7 using PRRS virus (a 'persistent' pathogen) as an example for calculation of sample sizes. However, within the programme, there is latitude to emphasize different components of the programme (by changing the frequency of sampling, sample size, or test that is utilized) to target an exotic pathogen of interest but with different epidemiological features than PRRS virus. The tasks of disease control and surveillance in the global pig industry are likely to become increasingly difficult given the frequency of emerging infectious agents over the last two decades (Arzt et al 2010; Meng 2012). When combined with the challenges associated with farmer implementation of good biosecurity practices (Casal et al 2007; Moore et al 2008; Hernandez-Jover et al 2012) it is clear that creation of logical and epidemiologically sound pathogen groupings such as those proposed in Chapter 1 will improve the feasibility of disease control plans. Chapter 1 goes on to describe ten principles that should be considered when developing biosecurity programmes. Leadership within the New Zealand pig industry will look to these principles as they begin implementation of a national biosecurity programme guided by the ILM-based strategic planning process detailed in Chapter 7.

Despite the generally good health of pigs in New Zealand, disease incursions have occurred. Aujeszky's disease was identified in 1976 though the actual incursion probably happened about three years earlier. Herd status accreditation and eradication programmes were not implemented until the late 1980s with the country being officially recognized as free of the disease in 2000. This effort represented a successful collaboration between government and industry. However, in 2003 PMWS appeared in an epidemiologically-related cluster of pig farms in the North Island and the outbreak was managed quite differently than the Aujeszky's outbreak some years before. While government was instrumental in assisting with the initial diagnosis and outbreak investigation of PMWS, there was reluctance by the government in accepting responsibility for an elimination programme. The commercial pig industry was left to either live with the disease and its future implications or undertake elimination through their own means; ultimately, the industry bought out the stock on the affected properties to bring the outbreak to a conclusion. In 2006 PMWS again surfaced in New Zealand, this time near Christchurch on the South Island and a detailed discussion of the outbreak

is included in Chapter 2. Aside from MAF support for some diagnostic testing during the initial outbreak investigation to rule-out Aujeszky's, PRRS, and classical swine fever, management of the outbreak was left to the industry despite the disease having been officially listed as an 'unwanted organism' by the government in 2003. The 2003 and 2006 PMWS outbreaks serve as an important reminder that even on an island with minimal importation of pig-based risk goods, diseases will predictably arise, emerge, or be introduced. Despite efforts to the contrary, New Zealand has experienced incursions of a number of plant and animal pests, and exotic insects in recent years (Pearson 2002) and it has been estimated that only 65% of these incursions were detected soon enough to make a decision about whether a response effort was even warranted. The situation is similar across the world even when considering important trade-limiting animal diseases such as foot and mouth disease in Japan (Muroga et al 2012), African Swine Fever in the Russian Federation (Oganesyan et al 2012), and classical swine fever in Europe (Stegeman et al 2000) for which significant time, energy, and money are being invested every year by countries with highly capable animal disease control authorities. The need for diligence in understanding the epidemiology of animal pathogens will continue for the foreseeable future.

While it seems inevitable that biosecurity hazards will continue to threaten the industry and regulation will need to change to meet the threats, a particularly troublesome threat i.e. the introduction of PRRS virus through importation of contaminated pork came to the forefront in New Zealand beginning in 2006. Chapter 3 of this thesis chronicles the event in detail but of particular concern in the ordeal were two important changes to the traditional approach to border security and biosecurity by MPI. First, the MPI risk analysis on PRRS concluded that approximately 1% of pork imported from PRRS affected countries would knowingly be contaminated with the virus and that post-border mitigation would have to be relied upon to manage the risk associated with that 1% contaminated product. The approach until this time was to attempt to exclude all known risk (virus) at the border, but with an acceptance that infrequently the risk (virus) would enter the country, and that well-established mitigation steps undertaken by responsible parties could be relied upon to avoid significant consequences of that introduction. By contrast in the PRRS example, virus would be knowingly brought into the country with the expectation that the average New Zealand consumer of pork could be relied upon to ensure none of the imported pork made its way into a pig's diet as untreated waste food. The second significant change to the biosecurity strategy around importation of risk

goods (fresh pork) was the development of a novel mitigation strategy for meat termed as ‘consumer-ready cuts’. While it makes some intuitive sense that not all parts of a carcass are equally risky in terms of virus transmission, no research has been done anywhere in the world, including New Zealand, to substantiate the effectiveness of using consumer-ready cuts of three kg or less in weight as a post-border risk mitigation strategy. Indeed, novel risk mitigation strategies will continue to be proposed as ways to meet the increasing global demand for animal protein; the need for scientists to be actively engaged in research and policy development in the areas of import risk analysis, surveillance, biosecurity, and trade is critically important (Hueston 2003; King 2004; Pfeiffer 2006).

Since publication of this analysis of the risk of introduction and spread of porcine reproductive and respiratory syndrome virus through importation of raw pigmeat into New Zealand, considerable additional work has been undertaken and a number of iterative changes have occurred to the underlying model based on stakeholder input. Indeed, the structure, assumptions, and parameter settings of the analysis remain in disagreement between analysts used by NZPork and those used by the Ministry of Primary Industries. A legal case that deals specifically with the import health standard for fresh pork into New Zealand from PRRS positive countries (with heavy reliance on the risk assessments that have been completed) remains under consideration by the New Zealand Supreme Court as of September 28, 2013.

Between the initial risk modelling published in 2008 and the most recent iteration produced by MPI, significant changes were made to the structure of the stochastic model in four areas with fewer substantive changes to the data or assumptions that were used to parameterize the model. First, changes to the model were incorporated to more correctly and flexibly estimate the potential for release of PRRS virus into New Zealand including introduction of two new variables that accounted for the type of pork product/cut that would be imported and the likelihood that the imported pork was sourced from a PRRS positive country. Second, a number of additional variables were added to more discretely estimate the loss in viral infectivity during slaughter, transportation, pork processing, and food preparation. Third, significant work was done to more accurately estimate the amount of pork scraps that were generated annually in New Zealand (from both home and commercial sources), the nature of those pork scraps (raw or partially cooked/processed), and the distribution of pork scraps to backyard pigs (frequency, size of scrap, and number of pigs per backyard herd) (Pearson et al 2009).

The model reported in this thesis dealt only with home-generated scraps, but later versions made use of new data to include processing by food service establishments as well as by home utilisation of pork. Fourth, a method was devised to estimate the 'infectiousness' of a pork scrap of a given size using a recent study on PRRS infectious dose (Hermann et al 2005).

After incorporating these changes into the model, a number of questions still remain as to the best values to be used in parameterizing each of the model variables. Using very similar versions of the model but with different input values, substantially different estimates of the annual risk of PRRS virus incursions have been produced by the two analytical groups, each of which has also strongly criticised limitations in the choice of parameter values and analytical assumptions by the other group. Using values supported by the pig industry stakeholders, the model suggests a median value of approximately one incursion per 10 years while the values supported by the government produce a median estimate of approximately one incursion per 507 years (mean value = 1227 years).

Extensive sensitivity analysis has been undertaken by the analysts working with the pig industry. Three model variables have been found to be most influential in estimating the risk of PRRS virus incursion when using the most recent versions of the stochastic model. The first influential variable describes the proportion of pork consumed in New Zealand which will be imported from PRRS infected countries, the second describes the proportion of imported pork which would be released into New Zealand in raw form (high risk) as compared to being imported then voluntarily cooked or processed in a manner that would destroy PRRS virus, and the third describes the proportion of imported pork from PRRS positive countries that can be expected to harbour contagious PRRS virus. In addition to their independent influence on the model outputs, when these variables are jointly varied their effect on the model output largely accounts for the difference in predicted frequency between the two modelling groups. If all three factors are given values at the low end of their plausible range, outbreak frequencies similar in magnitude to the government estimates are obtained. If one or more factors are given values in the middle or upper end of the plausible range, values similar to those obtained by the analysts working with the pig industry result. This is the core of the continuing debate. While the variables described above are most influential, steps that have been added into the model over time that attempt to estimate the extent of viral

decay at almost every processing step post-slaughter also contribute to the variability in model outputs.

A persistent issue in all the discussions that have occurred over nearly four years has been a lack of new information or data that fundamentally improves the quality of the values (or distribution of values) that are used to parameterize each variable in the model. Unfortunately, without improvements to our knowledge of PRRS virus in the context of 'risk', as opposed to our knowledge of PRRS virus 'biology' (which we know a lot about), the debate around the issue is unlikely to come to any satisfactory resolution.

Several lessons were learned through the battle over the competing risk assessments described in Chapter 3 (and in other documentation related to this on-going debate[35]) and which led to further work focussed on generating additional data about the nature and frequency of contacts between the commercial and non-commercial pig industries. In this regard, a prospective study of the behaviours of both commercial and non-commercial pig owners was undertaken using postal surveys and interviews; results of the study were presented in Chapter 4. Specifically, the study aimed to generate data that would describe the frequency and distance of movements of pigs, semen, and other potential disease vectors within and between the commercial and non-commercial sectors of the New Zealand pig industry. The study found that the overall frequency of interaction was modest but that because non-commercial sites out-numbered commercial sites by perhaps as much as 50 to one, any biosecurity lapses such as non-compliance with the waste food feeding regulations, would have a significant potential to have secondary effects in the commercial industry. This study found that while there are a substantial number of truly non-commercial pig holdings that seem to have little identifiable contact with the commercial industry, there is another sector of the industry described as 'para-commercial' that exist in between the non- and commercial sectors. These para-commercial farms have frequent contact within their sector (typically through movement and sale of weaner pigs) and outside their sector providing an indirect connection between non-commercial farms and commercial farms. Based on this study, their self-reported activities and frequency of contact with other pig holdings support the findings of the PRRS outbreak modelling reported in Chapter 4 whereby even when a PRRS virus outbreak started on a non-commercial peri-urban piggery, the

[35] http://www.biosecurity.govt.nz/ihs/pig-meat-from-canada-eu-mexico-usa.htm, accessed December 31, 2012.

outbreak reached the commercial industry in about 8% of the simulations. Fundamental to the issue of controlling disease transmission amongst pig holdings in New Zealand is managing the interface between commercial and non-commercial holdings. This issue has been important for other notable pathogens including avian influenza (Graham et al 2008) and other disease with zoonotic potential (Zinsstag et al 2011). Other authors have pointed out the need for, and difficulty of implementing traceability and premises identification systems (Schwägele 2005; Hernández-Jover et al 2009). The National Animal Identification and Tracing[36] programme is currently being implemented in the New Zealand cattle industry and will link people, premises and livestock movements into a single database; the timetable for including pigs into the national scheme is unknown.

Results of the studies described in Chapters 3 and 4 highlighted the need for the commercial industry to urgently assess the exotic disease surveillance capabilities that currently existed in the industry. In response to this, two additional studies (described in Chapters 5 and 6) were initiated. Given the dominant role of ruminant livestock production in New Zealand relative to pig production, it is not surprising that the existing veterinary diagnostic structure is biased toward an expertise in ruminant disease pathology and diagnostic testing for important diseases of sheep and cattle. This, combined with the knowledge that very few veterinarians actually service pig clients, suggested that inexperienced or non-technical people may end up being involved with collection or analysis of samples generated as part of a future pig disease surveillance system. Chapter 5 described a project targeted towards understanding the effect mishandled or improperly collected blood samples might have on the resulting diagnostic testing results returned from a typical antibody detecting ELISA assay. While numerous studies have been published assessing the performance of competing serological (Cho et al 1997) or molecular (Gerber et al 2012) assays on samples of known status, the work described in Chapter 5 remains the single study that has specifically investigated the effect of sample quality (of porcine blood) on ELISA performance. Eleven blood sample mishandling events such as haemolysis, repetitive freeze-thawing, and high ambient temperatures, similar to what might be expected in a real-life setting, were simulated in a laboratory. Only very high levels of haemolysis had significant effect on sample titres but even then, would only have a practical effect if a

[36] National Animal Identification and Tracing programme, http://www.nait.co.nz/, accessed January 21, 2013.

titre were close to the positive cut-off level for the test. Other maltreatments appeared to have only a negligible effect on titre and minimal effect on interpretation of the test result on a herd basis. Since the time this work was completed the author has repeated similar work using avian blood which also represents the only work of its kind in that species (Kurian et al 2012). Information on the effect of sample mishandling on ELISA results will provide information very useful to New Zealand and the rest of the global pig industry.

Related to the need to assess current and future surveillance capabilities in the industry, Chapter 6 described the results of an analysis of data collected during the first eleven years of the PigCheck system. The value of PigCheck to farmers in its current state is not well understood[37] though individually, it does appear farmers do crudely assess their PigCheck data with or without the assistance of their veterinarian. What had not been attempted until this time was a formal analysis of the entire data set to evaluate the overall quality of the data, consistency of reporting among abattoirs, the existence of any temporal trends or seasonality, or simply to establish a benchmark of lesion prevalence across the industry. Eighty-eight percent of the pig-level data was retained for analysis suggesting data quality over the 11 years was reasonably good. However, only 80% of the data records (i.e. lot-level data) were retained suggesting that lots comprised of only a few pigs were more likely to be dropped from the analysis; most records that were dropped from the analysis were due to missing owner identification data reinforcing the difficulty in collecting disease information from small (*sic* non- or para-commercial) farms. Interestingly, the most prevalent conditions across the 11 year time series were antero-ventral pneumonia (7.57%) and pleuropneumonia (11.43%); both are lesions related to common, easily-diagnosed diseases (*M. hyopneumoniae* and *A. pleuropneumoniae*) for which significant effort is invested to control or eradicate. On the positive side however, ten of the 15 lesions shown to have a significant trend over the 11-year period were decreasing. In the final analysis, the PigCheck systems operates at a low cost, is managed by a quality assured third-party that includes collection of data by trained inspectors, and makes the data available to farmers (and their nominated persons) on a near real-time basis all of which appear to support its use in a future surveillance system. While abattoir-based lesion recording systems are present in various parts of the world including Great Britain (Sanchez-Vazquez et al 2011),

[37] Clement F. Personal communication, September 15, 2010.

Netherlands (Blocks et al 1994), Scandinavian countries (Olsson et al 2001), and are further augmented through 'slaughter checks' conducted by practicing veterinarians, their formal integration into national surveillance programmes does not appear to have occurred. PigCheck however appears to be well-placed for integration into a national disease surveillance system based on its extensive geographical representation of the industry, low cost, and modern data capture and reporting system.

The commercial pig industry is supported through an active and capable levy-funded organisation called NZ Pork. The organisation's mandate is '*to help in the attainment, in the interests of pig farmers, of the best possible net on-going returns for New Zealand pigs, pork products and co-products*'[38] and part of their strategy for achieving this is to establish a comprehensive biosecurity programme for the industry. In the past, NZ Pork has created a number of initiatives, communications, and training programmes to advance their efforts in improving biosecurity on farms but these have tended to be a result of independent and uncoordinated efforts. In 2012, a project was undertaken to establish a comprehensive biosecurity programme for the industry using a strategic planning tool called Investment Logic Mapping (ILM); the process and its output are described in detail in Chapter 7. The ILM framework was developed by the Victorian (Australia) government over the last ten years and provides an efficient means for a group of decision-makers to achieve consensus on problems to be solved, benefits to be realized by solving the problems, strategies to achieve the solutions, and key performance indicators to monitor progress toward achieving the desired benefits. Through facilitated discussions, the ILM was developed and it became clear that design and implementation of a national disease surveillance programme was an important strategy would help in achieving a solution to several of the problems that had been identified. In addition, the ILM framework that was conducted in such a way as to be useful for NZ Pork as they commenced negotiations with MPI on their relative contributions toward readiness and response plans for exotic diseases, as dictated by GIA. A proposed national exotic disease surveillance plan was designed and costed as one of the outputs of the ILM process. While the current plan is focussed on PRRS surveillance for reasons described in Chapter 3, the surveillance framework is flexible to accommodate testing for alternate or additional pathogens by changing sampling

[38] http://www.pork.co.nz/AboutUs.aspx, accessed December 31, 2012.

frequency, sample sizes, or emphasising investment in one surveillance component of the plan more than another.

The need for a robust biosecurity and surveillance strategy in the NZ pig industry is urgent and will necessarily be borne from industry leaders and farmers. Within the industry lies the expertise to formulate and implement a successful strategy. However, this strategy on its own will be unlikely to completely protect the industry due to its significant overlap with the non-commercial pig industry. The substantial and largely unregulated non-commercial sectors of the pig industry require immediate investment by the government to ensure they are adequately monitored for incursions of exotic disease.

References

***Anonymous.** Review of the Biosecurity (Meat and Food Waste for Pigs) Regulations 2005. *Ministry of Agriculture and Forestry - Enforcement Group*, Wellington, 2008

***Anonymous.** Generation and disposal of food scraps. *UMR Research*, Wellington, New Zealand, 2011

Arzt J, White WR, Thomsen BV, Brown CC. Agricultural diseases on the move early in the third millennium. *Veterinary Pathology* 47, 15-27, 2010

Blocks GHM, Vernooy JCM, Verheijden JHM. Integrated quality control project: Relationships between pathological findings detected at the slaughterhouse and information gathered in a veterinary health scheme at pig farms. *Veterinary Quarterly* 16, 123-7, 1994

Casal J, De Manuel A, Mateu E, Martín M. Biosecurity measures on swine farms in Spain: Perceptions by farmers and their relationship to current on-farm measures. *Preventive Veterinary Medicine* 82, 138-50, 2007

Cho HJ, McNab B, Dubuc C, Jordan L, Afshar A, Magar R, Prins S, Eernisse K. Comparative study of serological methods for the detection of antibodies to porcine reproductive and respiratory syndrome virus. *Canadian Journal of Veterinary Research* 61, 161-6, 1997

Desrosiers R. Transmission of swine pathogens: different means, different needs. *Animal Health Research Reviews* 12, 1-13, 2011

Gerber PF, O'Neill K, Owolodun O, Wang C, Harmon K, Zhang J, Halbur PG, Zhou L, Meng XJ, Opriessnig T. Comparison of commercial real-time RT-PCR assays for reliable, early and rapid detection of heterologous strains of porcine reproductive and respiratory syndrome virus (PRRSV) in experimentally infected or negative boars using different sample types (semen, oral fluids, serum, blood swabs). *Journal of Clinical Microbiology*, 2012

Graham JP, Leibler JH, Price LB, Otte JM, Pfeiffer DU, Tiensin T, Silbergeld EK. The animal-human interface and infectious disease in industrial food animal production: rethinking biosecurity and biocontainment. *Public Health Reports* 123, 282-99, 2008

Hermann JR, Munoz-Zanzi CA, Roof MB, Burkhart K, Zimmerman JJ. Probability of porcine reproductive and respiratory syndrome (PRRS) virus infection as a function of exposure route and dose. *Veterinary Microbiology* 110, 7-16, 2005

Hernandez-Jover M, Taylor M, Holyoake P, Dhand N. Pig producers' perceptions of the Influenza Pandemic H1N1/09 outbreak and its effect on their biosecurity practices in Australia. *Preventive Veterinary Medicine* 106, 284-94, 2012

Hernández-Jover M, Schembri N, Toribio JA, Holyoake PK. Evaluation of the implementation of new traceability and food safety requirements in the pig industry in eastern Australia. *Australian Veterinary Journal* 87, 387-96, 2009

Hueston WD. Science, politics and animal health policy: epidemiology in action. *Preventive Veterinary Medicine* 60, 3-12, 2003

King L. Impacting policy through science and education. *Preventive Veterinary Medicine* 62, 185-92, 2004

Kurian A, Neumann EJ, Hall WF, Marks D. Effects of blood sample mishandling on ELISA results for infectious bronchitis virus, avian encephalomyelitis virus and chicken anaemia virus. *Veterinary Journal* 192, 378-81, 2012

Meng XJ. Emerging and Re-emerging Swine Viruses. *Transbound Emerg Dis*, 2012

Moore DA, Merryman ML, Hartman ML, Klingborg DJ. Comparison of published recommendations regarding biosecurity practices for various production animal species and classes. *Journal of the American Veterinary Medical Association* 233, 249-56, 2008

Muroga N, Hayama Y, Yamamoto T, Kurogi A, Tsuda T, Tsutsui T. The 2010 foot-and-mouth disease epidemic in Japan. *The Journal of veterinary medical science / the Japanese Society of Veterinary Science* 74, 399-404, 2012

Oganesyan AS, Petrova ON, Korennoy FI, Bardina NS, Gogin AE, Dudnikov SA. African swine fever in the Russian Federation: Spatio-temporal analysis and epidemiological overview. *Virus Research*, 2012

Olsson SO, Baekbo P, Hansson SO, Rautala H, Osteras O. Disease recording systems and herd health schemes for production diseases. *Acta veterinaria Scandinavica. Supplementum* 94, 51-60, 2001

***Pearson A, Neumann EJ, Sanson RL, Nicol K, Clement F.** Pig Movements Transmission of Exotic Diseases - Report Number 07 10 475. *Ministry of Agriculture and Forestry*, Wellington, New Zealand, 2009

***Pearson AB.** Review of New Zealand's Biosecurity Surveillance Systems (MAF Project Code Bio 111). *New Zealand Ministry of Agriculture and Forestry*, Wellington, New Zealand, 2002

Pfeiffer DU. Communicating risk and uncertainty in relation to development and implementation of disease control policies. *Veterinary Microbiology* 112, 259-64, 2006

Sanchez-Vazquez MJ, Strachan WD, Armstrong D, Nielen M, Gunn GJ. The British pig health schemes: integrated systems for large-scale pig abattoir lesion monitoring. *Veterinary Record* 169, 413, 2011

Schwägele F. Traceability from a European perspective. *Meat Science* 71, 164-73, 2005

Stegeman A, Elbers A, de Smit H, Moser H, Smak J, Pluimers F. The 1997-1998 epidemic of classical swine fever in the Netherlands. *Veterinary Microbiology* 73, 183-96, 2000

Stone M. PMWS in New Zealand: Surveillance, diagnosis, and risk factors for affected farms. *thesis*, Massey University, Palmerston North, NZ, 2005

Zinsstag J, Schelling E, Waltner-Toews D, Tanner M. From "one medicine" to "one health" and systemic approaches to health and well-being. *Preventive Veterinary Medicine* 101, 148-56, 2011

Appendix 1 - Statement of contribution to doctoral thesis containing publications

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STATEMENT OF CONTRIBUTION TO DOCTORAL THESIS CONTAINING PUBLICATIONS

(To appear at the end of each thesis chapter/section/appendix submitted as an article/paper or collected as an appendix at the end of the thesis)

We, the candidate and the candidate's Principal Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of Candidate: Eric James Neumann

Name/Title of Principal Supervisor: Mark Stevenson

Name of Published Research Output and full reference:

Neumann EJ. Disease Transmission and Biosecurity. In: Zimmerman JJ, Karriker LA, Ramirez A, Schwartz KJ, Stevenson GW (eds). Diseases of Swine. Pp 141-64. Wiley-Blackwell, Chichester, West Sussex, 2012

In which Chapter is the Published Work: Chapter 1. Disease transmission and biosecurity

Please indicate either:

- The percentage of the Published Work that was contributed by the candidate: 100%
  and / or
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DN: cn=Eric Neumann, o=Massey University, ou=EpiCentre, email=e.neumann@massey.ac.nz, c=NZ
Date: 2013.01.29 08:46:48 +13'00'

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Name of Candidate: Eric James Neumann

Name/Title of Principal Supervisor: Mark Stevenson

Name of Published Research Output and full reference:

Neumann EJ, Dobbinson SA, Welch EM, Morris RS. Descriptive summary of an outbreak of porcine post-weaning multisystemic wasting syndrome (PMWS) in New Zealand. New Zealand Veterinary Journal 55, 346-52, 2007

In which Chapter is the Published Work: Chapter 2. Descriptive summary of an outbreak of porcine post-weaning multisystemic wasting syndrome (PMWS) in New Zealand

Please indicate either:

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DN: cn=Eric Neumann, o=Massey University, ou=EpiCentre, email=e.neumann@massey.ac.nz, c=NZ
Date: 2013.01.29 08:46:48 +13'00'

Candidate's Signature

29 Jan 2013
Date

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29 Jan 2013.
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Name of Candidate: Eric James Neumann

Name/Title of Principal Supervisor: Mark Stevenson

Name of Published Research Output and full reference:

Neumann EJ, Morris RS, Sujau M. Analysis of the risk of introduction and spread of porcine reproductive and respiratory syndrome virus through importation of raw pigmeat into New Zealand. New Zealand Veterinary Journal 55, 326-36, 2007

In which Chapter is the Published Work: Chapter 3. Analysis of the risk of introduction and spread of porcine reproductive and respiratory syndrome virus through importation of raw pigmeat into N

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Digitally signed by Eric Neumann
DN: cn=Eric Neumann, o=Massey University, ou=EpiCentre, email=e.neumann@massey.ac.nz, c=NZ
Date: 2013.01.29 08:46:48 +13'00'

Candidate's Signature — 29 Jan 2013 — Date

Principal Supervisor's signature — 29 Jan 2013 — Date

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Name of Candidate: Eric James Neumann

Name/Title of Principal Supervisor: Mark Stevenson

Name of Published Research Output and full reference:

Neumann E, Pearson A, Sanson R, Nicoll K, Clement F. The frequency and distance of movements of pigs and semen between commercial and non-commercial piggeries in New Zealand. New Zealand Veterinary Journal, XX:XX-XX, 2012. http://dx.doi.org/10.1080/00480169.2012.715377 (First published online July 27, 2012)

In which Chapter is the Published Work: Chapter 4. The frequency and distance of movements of pigs and semen between commercial and non-commercial piggeries in New Zealand

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DN: cn=Eric Neumann, o=Massey University, ou=EpiCentre, email=e.neumann@massey.ac.nz, c=NZ
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Candidate's Signature

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Date

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Name of Candidate: Eric James Neumann

Name/Title of Principal Supervisor: Mark Stevenson

Name of Published Research Output and full reference:

Neumann EJ, Bonistalli K. Effect of blood sample handling post-collection on Erysipelothrix rhusiopathiae antibody titres. The Veterinary Journal 180, 325-9, 2009

In which Chapter is the Published Work: Chapter 5. Effect of blood sample handling post-collection on Erysipelothrix rhusiopathiae antibody titres

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DN: cn=Eric Neumann, o=Massey University, ou=EpiCentre, email=e.neumann@massey.ac.nz, c=NZ
Date: 2013.01.29 08:46:48 +1300'

Candidate's Signature

29 Jan 2013
Date

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