

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

Aspects of *Trichinella spiralis* in New Zealand

A thesis presented

*in partial fulfilment of the requirements for the degree of
Master of Veterinary Studies in Epidemiology at Massey University*

Esther Katharine Barr Richardson

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

2006

Abstract

In New Zealand, *Trichinella spiralis* appears absent from commercial pigs, and is not a significant cause of zoonotic disease. Surveillance testing at slaughter has not ever detected *T. spiralis* in a commercially raised pig in New Zealand, yet many importing countries still require individual testing of all pig carcasses for export. This thesis comprises four studies designed to evaluate the risk of *T. spiralis* infection in commercial pigs in New Zealand.

In the first study, the prevalence of *T. spiralis* was surveyed in selected populations of rats, cats, stoats and weasels from landfills, piggeries and Department of Conservation lands as they are considered potential reservoirs of *T. spiralis* for domestic pigs. No positive samples were detected in this survey. The second study investigated rodent activity and baiting efficacy on three commercial piggeries in the Manawatu region of New Zealand over 72 weeks. This study found that while baiting and on-farm sanitation can effectively control rodents, the efficacy of the control depends largely on staff commitment.

The third study used a mail questionnaire sent to 123 piggeries, to survey current management practices on commercial piggeries that could pose a risk for *Trichinella* transmission. The survey had a 69% response rate and found that risky management practices occur infrequently in commercial piggeries.

Lastly, a quantitative risk model was developed comparing individual carcass testing with alternative risk management strategies to assess the annual probability that a consumer in an importing country will eat a pork product of New Zealand origin containing at least one larva per gram of *T. spiralis*. Offals were found to always be safe. However, the unrestricted risk for fresh pork was over one in a million (1.87×10^{-5}), which was above the safety threshold and therefore various risk management options were considered. The strategy of only exporting pigs reared in certified, confined commercial herds has now been accepted and is in place by the importing country. This means that individual carcass testing is no longer compulsory for every exported pig carcass.

The overall conclusion from this research established a very low risk of *T. spiralis* infection and transmission in New Zealand commercial piggeries. These findings have directly led to successfully changing export legislation by removing compulsory carcass testing pre-export, which has advanced New Zealand's ability to competitively export high quality pork and pork products.

Acknowledgements

There are so many people to thank. Throughout this degree program I have been constantly amazed at how friendly and willing people are to help me and give me their time and advice. The EpiCentre, the Ecology department, IVABS as well as the greater Massey University community has such a wealth of knowledge, expertise and facilities which have been fundamental to my long but rewarding Masters program. People of all ages and cultures mix to make a wonderful combination and I couldn't have asked for more passionate, intelligent and friendly people to work with.

Exceptional thanks to my two supervisors, William Pomroy, and Murray Potter who have given excellent support and advice to me over the years. I really appreciate their willingness to go through my work and help me understand my thesis topic and the many factors involved with producing and writing a quality piece of research.

There are several other people who have been highly instrumental in the development of my masters program that I would like to extend my sincere thanks to; Ron Jackson, Solis Norton, Cord Heuer, Roger Morris, Nigel Perkins, and David Lawton.

I would like to thank Naomi Cogger for her extensive assistance and support in the development of the risk analysis work and model building.

The New Zealand Pork Industry Board has funded this project, for which I am very grateful; in addition to this, they have given me and my project their whole hearted support and also personal opportunities for me to develop inter-personal skills at meetings and seminars. Furthermore, I have had a lot of support and assistance from piggery owners and staff throughout the country. From running rodent control programs on their farms to filling in surveys, the piggery staff have been excellent to work with, and I would like to thank them greatly for their aid.

Moreover I would like to thank the DoC staff and landfill staff (Gary and Allan) for their help with collecting rats, stoats and weasels for sampling.

Philip Gendall was very helpful with his apt advice on survey structure and layout which was very helpful in setting up my questionnaire. Further to this I would like to acknowledge and thank Masood Sujau who very cooperatively set up an access database into which Naomi Cogger and Sean Kelly entered completed Pork Industry surveys.

Being here at the EpiCentre has been a special time that I will never forget. I warmly wish everyone all the best in their endeavours and thank them for sharing their company with me. Further to this some people have stood out to me for their support, encouragement, and hours of proof reading and chapter reviews:

Colleen Blair, Julie Dunlop, Mirtha Gimenez, Kathy Goodwin-Ray, Kevin Lawrence, Thibaud Porphre, Deb Prattley, Eric Neumann, Mark Stevenson, Simone Titus, Simon Verschaffelt.

My project has lead me to be involved in a range of departments and people:

Parasitology: Barbara, Anne, Sarah Clarke have all been involved with teaching me the practical side of parasitology. Growing worms is not as easy as one may imagine, and there are a lot more of them than you would think!

Ecology: Carol, Erica, Paul Barret have been very helpful with my thesis work, in particular with providing equipment and advice for trapping and tracking rats.

Food technology: Gary Radford very kindly lent me magnetic stirrers time and time again for digesting rats.

GIS: Matt Irwin was exceptionally patient and helpful while I was carrying out my Geographic information systems work. And yes, Matt is right; it isn't the computers fault if it doesn't work... it is mine!

Diane Richardson deserves a very special thank-you for her hours (and hours) of technical assistance at all times of the day, both in the lab and the field, without her aid support and encouragement the practical components of this thesis would not have been possible.

A big thank-you to my family and friends who have helped and encouraged me over the past three and a half years to carry out my studies.

My thesis project has not taken a direct path from beginning to end, but I think that the twists and turns have made it all the richer, and hopefully made me the wiser.

Table of Contents

Abstract	i
Acknowledgements	iii
Table of Contents	v
List of Figures	x
List of Tables	xiv
1 Literature review for <i>Trichinella</i> Study	1
<i>1.1 Introduction</i>	1
<i>1.2 Trichinella: pathogenicity, infectivity, reproduction and transmission</i>	1
<i>1.3 Detection and diagnostic tests for <i>T. spiralis</i> in muscle samples</i>	5
<i>1.4 How is <i>T. spiralis</i> a public health problem?</i>	8
1.4.1 <i>T. spiralis</i> in New Zealand.....	9
<i>1.5 Indicator species for <i>T. spiralis</i> in the environment</i>	13
1.5.1 Surveys on <i>T. spiralis</i> in Rats	15
1.5.2 <i>T. spiralis</i> in <i>Rattus norvegicus</i>	16
1.5.3 Potential hosts for <i>T. spiralis</i> in New Zealand.....	17
1.5.4 Effects of rodent control on trichinellosis in piggeries	18
<i>1.6 Rodents in New Zealand</i>	18
1.6.1 Rats in New Zealand	18
1.6.2 Mice in New Zealand.....	20
<i>1.7 Rats in New Zealand piggeries</i>	20
1.7.1 Rat behaviour in Piggeries	21
<i>1.8 Rodent control in piggeries</i>	21
1.8.1 Baits and bait placement	22
1.8.2 Monitoring Rodent Populations	24
1.8.3 Secondary effects of using poison baiting to control rodent populations	25
<i>1.9 Analysing rodent populations over space and time</i>	26
1.9.1 Logistic regression	26

1.9.2	Geographic Information Systems.....	27
1.10	<i>Risk assessment and control programs for Trichinella</i>	28
1.10.1	Risk assessments for food safety	28
1.10.2	Seven principles of HACCP	30
1.11	<i>Singaporean pork market</i>	30
1.12	<i>Aspects of Trichinella in New Zealand</i>	31
2	An investigation of selected populations of Cats, Rats, Stoats and Weasels for Trichinella spiralis in New Zealand Wildlife	32
2.1	<i>Introduction</i>	32
2.2	<i>Materials and Methods</i>	33
2.2.1	Experimental design.....	33
2.2.2	Data collection	34
2.2.3	Sample collection.....	35
2.2.4	Testing.....	35
2.2.5	Test verification	36
2.2.6	Analytical Techniques – Sample size calculations	36
2.2.7	Analysis of sampling technique	38
2.3	<i>Results</i>	39
2.3.1	Sample collection.....	39
2.3.2	Results of sample size calculations.....	43
2.3.3	Lab results	44
2.3.4	Test verification	44
2.4	<i>Discussion</i>	44
3	Survey of farm management practices on commercial piggeries in New Zealand	51
3.1	<i>Introduction</i>	51
3.2	<i>Method</i>	52
3.2.1	Study design.....	52
3.2.2	Descriptive analysis	53
3.2.3	Univariate analysis of rat activity	56

3.3 Results	56
3.3.1 Survey performance	56
3.3.2 Herd characteristics	57
3.3.3 Feedstuffs and sources	58
3.3.4 Farm environment	59
3.3.5 Rodent activity	61
3.3.6 Rodent control	62
3.3.7 <i>Trichinella</i>	64
3.3.8 Univariate analysis of rat activity	64
3.4 Discussion	64
4 Factors affecting rodent activity during intensive poison baiting on New Zealand commercial piggeries	69
4.1 Introduction to Rodent pests	69
4.2 Methods	70
4.2.1 Experimental Design	70
4.2.2 Monitoring Tunnels	72
4.2.3 Tunnel location	72
4.2.4 Poison baiting programme	73
4.2.5 Rat species and population structure	74
4.2.6 Data analysis	75
4.2.7 Spatial Analysis	75
4.2.8 Tracking rates – Binary data	76
4.2.9 Tracking rates – Categorical data	76
4.2.10 Risk factor analysis	79
4.2.11 Foot print size analysis	80
4.3 Results	81
4.3.1 Tunnels and bait stations	81
4.3.2 Tracking rates	85
4.3.3 Rat activity risk factors	88
4.3.4 Mouse activity risk factors	90

4.3.5	Goodness of fit for the logistic regression model	93
4.3.6	Rat populations in piggeries.....	94
4.4 Discussion		96
5	Quantitative risk assessment for exporting fresh chilled pork products.....	104
5.1	<i>Introduction</i>	104
5.1.1	Risk assessment	104
5.1.2	Process of a risk analysis	105
5.1.3	<i>T. spiralis</i> in New Zealand.....	106
5.1.4	Quantitative risk analysis for New Zealand pork.....	107
5.2	<i>Materials and Methods</i>	107
5.2.1	Risk assessment model	107
5.2.2	Generation of model outputs using Excel.....	113
5.2.3	Defining the model inputs.....	114
5.2.4	Risk assessment: Restricted estimates	118
5.2.5	Interpretation of model output values	121
5.2.6	Sensitivity Analysis	122
5.3	<i>Results</i>	122
5.3.1	Comparison between offal and pork for the unrestricted risk estimate	122
5.3.2	Comparison of unrestricted and restricted risk strategies for fresh pork	123
5.3.3	Sensitivity analysis results	124
5.4	<i>Discussion</i>	125
6	General discussion.....	130
Appendices.....		134
Appendix 2.1	– Standard operating procedures for Pepsin digest test.....	135
Appendix 2.2	– Letter introducing the study to Farmers	137
Appendix 2.3	- Copy of a reply letter sent to a farmer	138
Appendix 3.1	– Cover letter and survey form for commercial piggeries management survey	139
Appendix 3.2	– Thank-you letter	146

Appendix 3.3 - Raw data.....	147
Appendix 3.4 - Results of univariate analysis comparing rat activity with on-farm variables	160
Appendix 4.1– Digitised aerial photos.....	163
Appendix 4.2 – Rat SAS Analysis	166
Appendix 4.3 – Assessment of footprint size over time	168
Appendix 4.4 – Rats collected from three piggeries	169
Appendix 4.5– Sequential maps showing the change in rodent distribution over time.....	171
Appendix 5.1- Input values and distributions used in the unrestricted risk assessment model.....	186
Appendix 5.2 – Summary structure of the Risk analysis model.....	187
Appendix 5.3 – Descriptive results of model outputs under different situations.....	191
Appendix 5.4 – Appearance of quantitative risk assessment built in Excel	192
References	196

List of Figures

Figure 1.1 The lifecycle of <i>Trichinella</i> is direct, as only the infective stages passes between hosts and all developmental stages from first stage larvae (L1) through to the adult occur in the same host. Adapted from Kassai (1999).	4
Figure 1.2 Components of a risk analysis, including the steps of the risk assessment, as described by the World Organisation for Animal Health.	28
Figure 2.1 Rat dissection in the post mortem room at the Institute of Veterinary, Animal and Biomedical Sciences, Massey University. The diaphragm, masseter muscles and tongue were removed and tested for <i>T. spiralis</i>	35
Figure 2.2. Norway and ship rats were sourced from three different environment types.	40
Figure 2.3. Distribution of weights of Norway rats (top) and ship rats (bottom) collected from different locations throughout New Zealand. The black line is a normal curve.	42
Figure 2.4. Numbers of Norway rats and ship rats collected from eleven commercial piggeries.	43
Figure 3.1 Types of by-products fed by commercial piggeries.	58
Figure 3.2 Animal species, other than pigs, present on the piggery and in close proximity to buildings containing pigs.	59
Figure 3.3 Methods used by piggeries to dispose of dead pigs, piglets and afterbirth. ..	60
Figure 3.4 Percentages of high, medium and low rat activity identified on surveyed piggeries.	61
Figure 3.5 Percentages of high, medium and low mouse activity identified on surveyed piggeries.	62
Figure 3.6 Types of rodent control used on commercial piggeries.	63
Figure 3.7 Brands of bait used by commercial piggeries.	63
Figure 4.1. Photograph and diagram of a monitoring tunnel.	72
Figure 4.2 Photographs of different bait stations used on the piggery.	74
Figure 4.3. Photographic representation of categories of rat activity, from left 0- very light, 1- light, 2 - moderate and 3- heavy.	78

Figure 4.4. Photographic representation of categories of mouse activity, from left 0- very light, 1- light, 2 - moderate and 3- heavy..... 78

Figure 4.5. Prints were measured across the foot from the first to the last digit, as depicted by line "s" for front feet (shown on the right) and back feet (shown on the left).81

Figure 4.6. A farm map of Piggery 1 showing the perimeter of the piggery with building outlines. Tracking rates (shown on the left) are a percentage of total nights tracked for each tunnel and are displayed as an estimation of activity within a 10 m radius of each tunnel to give a picture of activity for the area. This can be compared to the level of bait cover (shown on the right) provided at the intensive baiting stage on the piggery for each species where bait cover for rats is a 9 m radius from a station and for mice is a 3.6 m radius. 82

Figure 4.7. A farm map of Piggery 2 showing the perimeter of the piggery with building outlines. Tracking rates (shown on the left) are a percentage of total nights tracked for each tunnel and are displayed as an estimation of activity within a 10 m radius of each tunnel to give a picture of activity for the area. This can be compared to the level of bait cover (shown on the right) provided at the intensive baiting stage on the piggery for each species where bait cover for rats is a 9 m radius from a station and for mice is a 3.6 m radius. 83

Figure 4.8. A farm map of Piggery 3 showing the perimeter of the piggery with building outlines. Tracking rates (shown on the left) are a percentage of total nights tracked for each tunnel and are displayed as an estimation of activity within a 10 m radius of each tunnel to give a picture of activity for the area. This can be compared to the level of bait cover (shown on the right) provided at the intensive baiting stage on the piggery for each species where bait cover for rats is a 9 m radius from a station and for mice is a 3.6 m radius. 84

Figure 4.9. Proportion of tunnels tracked by each species, both species and proportion of overlap between species for three piggeries in the Manawatu. The commencement of baiting in week 4 is shown by the yellow diamond..... 85

Figure 4.10. The proportion of tunnels tracked by rodents in three Manawatu piggeries from November 2002 to April 2004, with 95% error bars..... 86

Figure 4.11. Tracking rates are displayed here as a binary result and categorical result. These tracking rates have been graphed against time for both mice and rats..... 87

Figure 4.12. Scatter graphs comparing the tracking rates of rat, mouse and species overlap in three Manawatu piggeries..... 88

Figure 4.13. The predicted value for rat tracking (left) and mouse tracking (right) versus the chi-squared residual of the outcome variable..... 93

Figure 4.14. The size of individual rat footprints (mm) over 74 weeks, along with overall rat tracking rate. 95

Figure 4.15. Scatter plot of rat footprint size against the average activity level observed in that building at the time the footprints were recorded. 95

Figure 5.1 The release assessment is outlined from selecting a pig to the arrival of the pork product into Singapore. Each step represents the effect that event is likely to have on hazard. Where the step is calculated the equation is shown, otherwise the step is an input value..... 108

Figure 5.2 Steps in the exposure assessment for calculating the likelihood of entry and exposure for an infected pork product. 112

Figure 5.3 The distribution of 1000 iterations from the model for the unrestricted risk estimate for pork. The position of the 50th and 95th percentiles are shown. ... 123

Figure 5.4 Box and whisker plots of the model outputs for the six different control strategies for *T. spiralis* in New Zealand pork products, illustrating the variation in the distribution of the outputs from each model, and comparing all models to the threshold value of one in a million. The 95th percentile is shown by a star..... 124

Appendix 4.1. Figure 1 Digitised aerial photos of Piggery 1 with inside and outside monitoring tunnel locations. 163

Appendix 4.1. Figure 2 Digitised aerial photos of Piggery 2 with inside and outside monitoring tunnel locations. 164

Appendix 4.1. Figure 3 Digitised aerial photos of Piggery 3 with inside and outside monitoring tunnel locations. 165

Appendix 4.2. Figure 1 The effect on the data of a “logit transformation”, by which binary data is transformed into linear data is shown..... 167

Appendix 4.3. Figure 1 Scatter plots of footprint size over time for each shed with more than 5 weeks of tracking rat activity. 168

Appendix 5.4. Figure 1 Front page of model, showing the unrestricted risk selected for assessment. 192

Appendix 5.4. Figure 2 Page two of the model contains changeable, market specific data. 193

Appendix 5.4. Figure 3 The results for the unrestricted risk assessment, where pepsin digest testing is used. 194

Appendix 5.4. Figure 4 Definitions used in the model. 194

Appendix 5.4. Figure 5 A range of values used to act on different variables to model the affects of a control method..... 195

Appendix 5.4. Figure 6 The input values are calculated by equations nested in the risk assessment pathways. 195

List of Tables

Table 1.1. Worldwide distributions and characteristics of the various species of <i>Trichinella</i> (Poizio and Zarlenga 2005).	3
Table 1.2. Three main methods for detecting <i>Trichinella</i> infections.	7
Table 1.3. A summary of international articles reporting the prevalence of trichinellosis in humans and pigs.	10
Table 1.4. Natural <i>T. spiralis</i> infections between 1931 and 2005 identified in a range of New Zealand species from outbreaks and surveys.	12
Table 1.5. <i>T. spiralis</i> infections identified in New Zealand pigs from routine testing for the domestic and export market.	13
Table 1.6 Results of pepsin digest testing for <i>T. spiralis</i> in exported meat from New Zealand.	13
Table 1.7. Differentiating characteristics between rat species in piggeries (Innes 1990; Moors 1990).	18
Table 1.8. A summary from the Department of Conservation of products registered for use as of 2000 for rodent control in New Zealand (O'Connor and Eason 2000).	23
Table 2.1 Details of the 16 sites around New Zealand from which rats, cats, stoats and weasels were collected and tested for <i>T. spiralis</i>	39
Table 3.1 The system used to uniquely identify high, medium, or low activity.	55
Table 3.2 Brand name, toxicant and distributor for eight rodenticide baits available in New Zealand.	55
Table 3.3 Survey questions that had high non-response rates.	57
Table 3.4 Number of pigs in surveyed piggeries.	58
Table 3.5 Summary of uncategorised ratings of rodent activity on farms.	61
Table 4.1 Piggery and building area, number of baiting tunnels and pigs from three Manawatu piggeries.	71
Table 4.2 The study design outlines the date, week and study period of each sample collected from November 2002 to April 2004 (74 weeks). The change in baiting	

practise between study periods by is highlighted through using different colours for each study period.	71
Table 4.3 Definitions for categories of rodent activity used to grade papers from each monitoring tunnel.	77
Table 4.4 Data structure of the multivariate analysis involving repeated sampling from a tunnel that was nested within both a shed, and a farm. The categories of the outcome and explanatory variables involved in the multivariate analysis are also defined.	79
Table 4.5. Results from a logistic regression model assessing the effects of study week, piggery, position of tunnels and class of pig on rat activity. The odds ratios are given with the upper and lower 95% confidence intervals (CI) of the odds ratio.	90
Table 4.6. Results from a logistic regression model assessing the effects of week, piggery, position of tunnels and pig type on mouse activity. The odds ratios are given with the upper and lower 95% confidence intervals (CI) of the odds ratio.	92
Table 4.7. Date, number, species and weights of dead rats from three Manawatu piggeries.	94
Table 5.1 Risk management strategies to mitigate the residual risk of <i>T. spiralis</i> in pork.	119
Table 5.2 The sensitivity analysis for input variables of the annual probability of exposure to <i>T. spiralis</i> to a consumer, in New Zealand pork.	125
Appendix 4.4. Table 1 Specifics on rats collected from three piggeries in the Manawatu.	169
Appendix 5.2. Table 1 Values, calculations and definitions for each step in the release assessment. The unit of consumption in this study was taken as a pork product. As there is a wide range in the size of any given pork product, units are stated per gram of pork product consumed.	187
Appendix 5.2. Table 2 Values, calculations and definitions for each step in the Exposure assessment.	190
Appendix 5.3. Table 3 The 25th (Q1) and 75th percentiles (Q3), inter quartile range (IQR) median and range are used here to describe the distribution of the 1000 output iterations from the six different model scenarios.	191

1 Literature review for *Trichinella* Study

1.1 Introduction

Trichinella spiralis has become an issue for the development of an export market for New Zealand pork and pork products due to the perceived risk of contracting trichinellosis through consuming pork from domestically raised pigs. This chapter reviews the biology of *T. spiralis*, its significance as a global pathogen and previous findings of the parasite in New Zealand. The chapter then reviews potential hosts and transmission pathways for the parasite, followed by an overview of the biology, behaviour and control methods for the most commonly associated hosts for the parasite in New Zealand, rats and mice. Lastly this chapter examines different epidemiological tools and methods used in later chapters.

1.2 *Trichinella*: pathogenicity, infectivity, reproduction and transmission

Trichinellosis is a disease caused by parasitic nematodes from the genus *Trichinella*. Parasitic nematodes are animals which feed from and often live inside another “host” animal without any benefit to that host (Geddes and Grosset 2003). The genus *Trichinella* is a member of the order Enoplida, and superfamily Trichuroidea (Kassai 1999). This genus can establish in a wide variety of hosts, including humans and domestic animals, and is endemic in many parts of the world. Within the genus are eight recognised species, and three genotypes that are yet to be given a taxonomic grouping. *Trichinella* species principally parasitise mammalian hosts, however some species also parasitise birds and reptiles such as crocodiles (Pozio and Zarlenga 2005). *Trichinella* species differ by their host specificity, ability to persist in the host, and their resistance to environmental temperatures and environmental conditions. These factors determine the distribution and physiological tolerances of each species, as illustrated in Table 1.1.

Trichinella species also differ widely in their level of infectivity and pathogenicity for different hosts. The reproductive capacity index (RCI) compares how many larvae are present in the muscles against the number of larvae ingested by the host (Pozio 2000). Studies using rats found that both *T. spiralis* and *T. pseudospiralis* established infections, but the RCI was four times higher for *T. spiralis* than *T. pseudospiralis*

(Pozio, La Rosa et al. 1992). The other six *Trichinella* species tested did not establish infection in the rat host.

Similarly, *Trichinella* species differ in their level of pathogenicity in humans. Trichinellosis has caused numerous human infections and deaths in a range of countries since it was first recognised in 1835 (Pozio 2000; Pozio 2001). Although actual studies of pathogenicity such as RCI, have not been carried out in humans, comparisons can be made from clinical cases of infection by different species. Humans have been infected by *T. spiralis*, *T. nativa*, *T. britovi*, *T. nelsoni*, *Trichinella T6* and *T. murrelli* (Kapel 2000; Pozio and Zarlenga 2005). The number and severity of these infections vary greatly between the species (Pozio, La Rosa et al. 1992). *T. spiralis* is the major cause of trichinellosis in humans largely due to the high numbers of larvae that are produced by this species which can then circulate within the host (Kapel 2000). It has been estimated that ingestion of 500 *T. spiralis* larvae is likely to cause severe pathogenic effects (Kassai 1999), or 5 larvae/g of the human host's body weight (Chandler and Read, 1961; as cited in (Bowman, Lynn et al. 2003)). Infections with *T. nativa* and *T. murrelli* can also be severe, but the number of cases are few, whereas even high larval burdens of *T. britovi* and *T. nelsoni* cause only moderate clinical infections in humans (Pozio, La Rosa et al. 1992; Pozio and Zarlenga 2005).

Trichinella is maintained in the environment by transmission between hosts through two separate but occasionally overlapping or interacting cycles. The two main transmission cycles for *Trichinella* involve either sylvatic hosts (sylvatic cycle), which relates to those living in forest areas and remote type environments, or domestic hosts (synanthropic cycle), where the host species live in areas of human habitation (Murrell and Pozio 2000; Kociecka, Boczon et al. 2003). In the sylvatic cycle the parasite is transmitted through the hunting and scavenging behaviour of omnivores and carnivores (Kapel 2000). Humans may influence the spread of *Trichinella* within this cycle through hunting and poor carcass disposal (Pozio 2000). The synanthropic cycle, better known as the domestic cycle, is perpetuated by human practices such as waste-food feeding to livestock that can directly transmit the parasite to the host, or through direct or indirect transmission between hosts (such as rats, cats, dogs and pigs) that live in domestic habitats (Pozio 2001).

Table 1.1. Worldwide distributions and characteristics of the various species of *Trichinella* (Pozio and Zarlenga 2005).

<i>Trichinella</i> species or genotype	Cycle	Encapsulated/ non-encapsulated	Potential hosts	Freeze resistance (days)	Distribution
<i>T. spiralis</i>	Domestic and Sylvatic	Encapsulated	Mammals	-15°C (~ 20 days)	Cosmopolitan
<i>T. nativa</i>	Sylvatic	Encapsulated	Mammals	-18°C (~ 5 years)	Arctic and Sub-arctic
<i>Trichinella</i> T6 ^a	Sylvatic	Encapsulated	Mammals	Frozen muscle (~3years)	Southern Canada, northern USA
<i>T. britovi</i>	Sylvatic	Encapsulated	Mammals	Frozen carnivore muscle (~11 months) Frozen porcine muscle (~3 weeks)	Temperate areas of the Palearctic region
<i>Trichinella</i> T8 ^b	Sylvatic	Encapsulated	Mammals	<i>Not defined</i>	South Africa and Namibia
<i>Trichinella</i> T9 ^c	Sylvatic	Encapsulated	Mammals	<i>Not defined</i>	Japan
<i>T. murrelli</i>	Sylvatic	Encapsulated	Mammals	Moderate freeze resistance ^d	USA
<i>T. nelsoni</i>	Sylvatic	Encapsulated	Mammals	No freeze resistance	Southern Africa
<i>T. pseudospiralis</i>	Sylvatic	non-encapsulated	Mammals, birds	No freeze resistance	Cosmopolitan
<i>T. papuae</i>	Sylvatic	non-encapsulated	Mammals, reptiles	<i>Not defined</i>	Papua New Guinea
<i>T. zimbabwensis</i>	Sylvatic	non-encapsulated	Mammals, reptiles	<i>Not defined</i>	South-eastern Africa

^a It has been demonstrated through interbreeding that *Trichinella* T6 is strictly related to *T. nativa*.

^b It has been demonstrated through interbreeding that *Trichinella* T8 is strictly related to *T. britovi*.

^c *Trichinella* T9 may be more closely related to *T. murrelli* than to *T. britovi* although T9 has generally been associated with *T. britovi* (O'Connor and Eason 2000).

^d *T. murrelli*, like *T. britovi*, demonstrated different tolerances to freezing depending on its host species.

T. spiralis is the primary cause of trichinellosis in humans. *T. spiralis* is the only *Trichinella* species that can be maintained in the domestic cycle, although other species may also establish infections in domestic animals (Pozio 2000; Pozio and Zarlenga 2005). Infection in domestic meat is related to poor animal husbandry practices and access by feral animals onto the farm (Angus 2003). In a study by Jovic et al. (2001) experimentally infected pork was buried and recovered at intervals. After 90 days, *T. spiralis* larvae remained infective. This illustrates the long term viability of *T. spiralis* in pork left at environmental temperatures. The persistence of *T. spiralis* provides a wide window of opportunity for other animals in the area to contract the parasite (Wakelin and Goyal 1996; Kociecka, Boczon et al. 2003).

T. spiralis has a direct lifecycle where both adult and larval stages occur in the same host (Kassai 1999; Bowman, Lynn et al. 2003), as outlined in Figure 1.1. Infection is passed from host to host through ingestion of infective L1 (first stage) larvae in muscle

tissue. The L1 larvae are enclosed in the muscle cells of the previous host. As the muscle cell is broken down by gastric fluids and bile in the alimentary tract, the infective L1 larvae are released into the small intestine. The L1 larvae develop to L4 larvae in the epithelium of the small intestine; they then emerge and mature into adult males and females which reproduce in the lumen of the small intestine. The time from ingestion to sexual maturation takes approximately 1 ½ - 3 days (Kassai 1999; Bowman, Lynn et al. 2003; Kociecka, Boczon et al. 2003).

The male dies after copulation and the fertilised female releases L1 larvae into lymph spaces in the small intestinal wall from day 6 post ingestion for up to 4-5 additional weeks. During this time the female produces 1000-2000 larvae (Kassai 1999). The L1 larvae enter the lymphatic system and veins of the small intestine, and proceed to migrate through the blood stream for a further 7-8 days as they mature and develop until the larvae are capable of invading skeletal muscle. Once in skeletal muscle, larvae enter the muscle cell where the larvae mature further into infective L1 larvae during the first 2-3 weeks (Bowman, Lynn et al. 2003). The larvae alter the muscle cells' metabolism to create a "nurse-cell" from the original muscle cell, within which the larva receives nutrients and remains viable inside the host for many years. The L1 remains in the muscle tissue until it is ingested by the next host (Corwin 1999; Kociecka, Boczon et al. 2003).

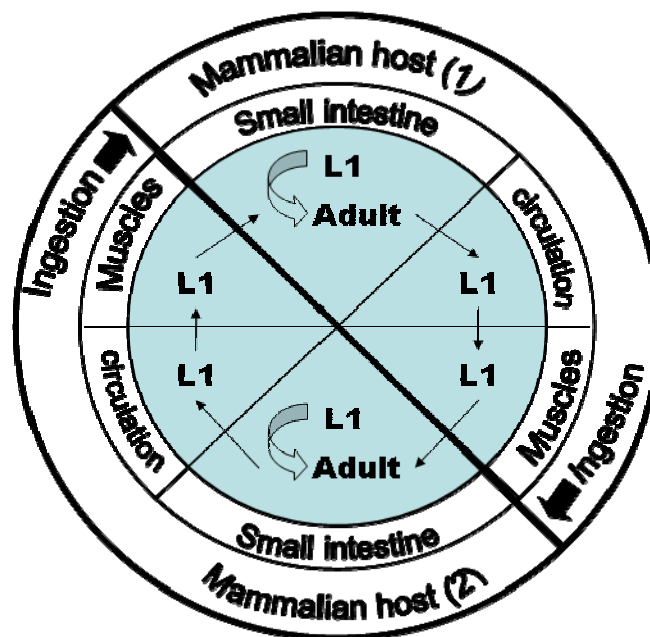


Figure 1.1 The lifecycle of *Trichinella* is direct, as only the infective stages passes between hosts and all developmental stages from first stage larvae (L1) through to the adult occur in the same host. Adapted from Kassai (1999).

T. spiralis is particularly well adapted to domestic animal hosts. Historically, omnivorous rats and pigs have been the primary domestic hosts associated with trichinellosis (Murrell and Pozio 2000). The traditional domestic cycle of *T. spiralis* on pig farms is a cycle which involves pig-to-pig transmission, or pig-to-rat-to-pig transmission, where the host becomes infected through scavenging an infected carcass or consuming untreated, infected swill (Twigg 1975; Smith 1985). Further to this, tail biting and faecal transmission (during the initial 1-2 days after having eaten infected meat) are potential means of transmission (Anon. 1974; Pozio 2000). Evidence suggests that vertical transmission does not occur in pigs, possibly because the particular structure of the porcine placenta does not allow direct contact between foetal and maternal blood (Hurnikova, Snabel et al. 2005; Webster and Kapel 2005).

More recently herbivorous hosts have been found to carry *T. spiralis*. Horses have been implicated as the primary cause of trichinellosis in France and Italy over recent years (Pozio 2001). The practice of eating raw horse meat in France and Italy has led to at least 13 outbreaks involving 3200 people in recent years (Boireau, Vallee et al. 2000). In 1981, Xu reported that rat carcasses were found in the first stomach of goats in Neimonggol province in China following necropsy (Takahashi, Mingyuan et al. 2000). Further studies in China by Xu published in 1997 noted the finding of rats in sheep stomachs (Liu and Boireau 2002). However, only in China has mutton and beef been reported to be infected with *T. spiralis* (Pozio 2001).

1.3 Detection and diagnostic tests for *T. spiralis* in muscle samples

Visual inspection of a carcass at slaughter cannot identify the presence of encysted larvae in muscle tissue; therefore, a post-mortem test must be used to identify a *Trichinella* infection. The sensitivity of disease detection is constrained by the minimum number of larvae per gram (LPG) of muscle that can be detected in a sample. For example, if the lowest possible parasite burden the test can detect is 1 larva per gram of muscle tissue, and the infected sample is infected with 1 parasite per 5 grams of or 0.2 larvae/g, then only infrequently would the infection be detected. In this case the sample would test negative for the parasite, when it was in fact positive. Poor sensitivity of detection by post mortem tests can lead to some meat testing negative for *T. spiralis* when it is actually infected.

A single *T. spiralis* female can produce 1000-2000 larvae over a 4-5 week period (Kassai 1999). The amount of meat from a 100 kg pig is approximately 55.5 kg (Wulf 2005). The minimum larval burden would be 0.018 – 0.036 larvae/g from one reproducing *T. spiralis* female if the larvae were evenly distributed throughout the carcass and no larvae were lost through defecation. However, *T. spiralis* is not evenly distributed throughout a carcass and the concentration of encysted larvae has been found to be at least 20% lower in skeletal muscle used for pork cuts, such as the hind leg or front leg, than in the diaphragm, which is the muscle commonly used for testing (Kapel, Webster et al. 1998).

Table 1.2 outlines the three main methods currently used for the detection of *Trichinella* species in meat. Due to the improvement in sensitivity, decrease in cost and also the increased number of samples that can be tested by pepsin digest compared to trichinostomy, pooled pepsin digests are the recommended diagnostic test for *Trichinella* for food safety and assurance work (Nockler, Pozio et al. 2000). The official test for meat inspection and food safety requirements in New Zealand is the pepsin digest method. Standardised recommendations for pooled sample digestion methods as stated by the International Commission on Trichinellosis (2003) are contained in the:

- World Organisation for Animal Health (OIE) Manual of Standards for Diagnostic Tests and Vaccines (Article 3.5.3)
- European Union Directive 84/319/EEC, amending the annexes to Council Directive 77/96/EEC
- The International Commission on Trichinellosis: Recommendations on Methods for the Control of *Trichinella* in Domestic and Wild Animals Intended for Human Consumption [Appendix I]

The pepsin digest test has a sensitivity appropriate to detect infection at a level likely to cause clinical trichinellosis in humans (Bessonv, Cuperlovic et al. 2003). This sensitivity is 1 larvae/g of muscle from a 5 gram sample of muscle (Gajadhar, Bisailon et al. 1997). In comparison, the trichinostomy test only has a test sensitivity of 3-5 larvae/g (European-Commission 2001). Kapel et al's (1998) findings suggested that a pig with a larval burden in its diaphragm of ~2.6 larvae/g would have a larval burden of ~2.1 larvae/g in the hind legs. Ingestion of 500 or more larvae can cause acute

trichinellosis in people (Gamble, Bessonov et al. 2000). Eating 200g or more of the hind leg of such a pig with levels of infection >2 larvae/g, were it poorly cooked or improperly cured, could cause trichinellosis in the consumer. This illustrates how larval burdens that could cause trichinellosis, may not be detected by trichinoscopy, but would be detected by using a pepsin digest.

Infections may not cause disease symptoms, but may still establish the parasite in a new host (Nockler, Pozio et al. 2000). Direct parasitological methods for the diagnosis of *Trichinella* have been found poor at detecting very low level infections (Gamble and Bush 1999; van Knapen 2000). In serological surveys, the enzyme-linked immunosorbent assay (ELISA) appears to be able to detect infected animals with larval burdens well below the levels detected by pepsin digest (Gamble, Brady et al. 1999). However, serological testing is not considered to be a reliable method to ensure the safety of meat products from *Trichinella* infection. This is due to the high numbers of false negatives that can result from light infections and the time lag for the host to develop an immunological response to the parasite after being infected (Smith 1987; Nockler, Pozio et al. 2000).

Table 1.2. Three main methods for detecting *Trichinella* infections.

Method	Sample examined	Sensitivity	Description of Technique
Trichinoscopy	Muscle	3-5 larvae/g for a 0.5-1 g sample (van Knapen 2000)	~1 g sample from the diaphragm, tongue, masseter, intercostals, triceps brachialis or quadriceps femoralis, is sliced thinly (~1 mm thickness) and squashed between two plate of glass. The “squashed” sample is examined microscopically (Vignau, Guardis et al. 1997).
Pepsin Digest	Muscle	1 larva/g from a 5 g sample (Nockler, Pozio et al. 2000)	1-5 g of muscle (from the same muscle groups as above) are digested in a solution of HCl, pepsin and water. The digest is then filtered and put through a sedimentation process to retrieve the encysted larvae.
Serology (ELISA)	Serum	~1 larva/100 g (Gamble and Bush 1999)	Although several serology tests are available, the enzyme-linked immunosorbent assay (ELISA) is the only serological method recommended by the ICT ^a . This method tests for <i>Trichinella</i> antibodies in the sera, and is sensitive to the magnitude and age of infection, as well as the individual physiology of the animal (Smith 1987; Nockler, Pozio et al. 2000).

^a ICT is the International Commission on Trichinellosis, the internationally accepted authority on *Trichinella* and trichinellosis.

1.4 How is *T. spiralis* a public health problem?

T. spiralis is classified as a List B disease by the World Organisation for Animal Health (OIE). The disease has been recognized as a public health issue for many years, but despite advances in the knowledge and control of the parasite, it is still a health and food safety problem for countries worldwide (Gajadhar and Gamble 2000).

In humans, initial symptoms of the disease include general discomfort, fever, chills, excessive sweating and occasionally diarrhoea (Kassai 1999). As the disease progresses, clinical signs may include facial oedema, muscle pains, and localised haemorrhages in small blood vessels below the skin, in the conjunctiva of the eye and in the nail beds. Symptoms can last for several weeks and further cardiovascular and neurological complications can occur (Kociecka, Boczon et al. 2003). In severe cases these complications have lead to deaths, but this is rare (European-Commission 2001). Clinical disease is treated medically with anthelmintics and may be treated simultaneously with glucocorticoids.

Several studies have been conducted to determine the cost of trichinellosis as a public health disease. In the United States between 1987-1990, there were on average about 131 cases of trichinellosis a year and the total cost of the disease was calculated to be \$781,578 which included the cost of hospitalisation and lost wages (Roberts, Murrell et al. 1994). More recent estimates of the cost of human and pig trichinellosis in the United States reach over 1 billion (US)dollars annually (Murrell and Pozio 2000). The European Union has had 3000-5000 human cases annually between 1990 and 2004, which has an economic impact in some regions, for example in France in 1985 the cost of trichinellosis was 1.5 million (US)dollars (Dupouy-Camet 2000; Kapel 2005). China has had 25,209 human cases and 220 deaths recorded since 1964, which creates economic consequences (Takahashi, Mingyuan et al. 2000). One case of economic loss was a Chinese abattoir which lost US\$550,000 between 1975 and 1985 due to having a high prevalence of infection in their slaughtered pigs (Takahashi, Mingyuan et al. 2000). Additional costs from the disease are incurred through ongoing compulsory testing of pig carcasses at slaughter. Testing for *T. spiralis* is a compulsory food safety standard in many developed parts of the world, even in countries where positive cases have not been found in commercially produced pork for 40 years or more (Pozio 1998; Enemark, Bjorn et al. 2000). Pozio (1998) estimated that the European Union could save about US\$420,000,000 annually if routine testing was stopped in some countries.

Table 1.3 outlines reports on trichinellosis from different parts of the world illustrating that the numbers of trichinellosis cases in humans and pigs vary widely depending on the country of origin. In countries such as China and Argentina, trichinellosis is considered to be a continuing human health problem.

1.4.1 *T. spiralis* in New Zealand

In New Zealand, trichinellosis is an extremely rare zoonotic disease (Liberona and MacDiarmid 1988; Paterson, Black et al. 1997). Within the genus *Trichinella*, only *T. spiralis* has been detected in New Zealand. This species has caused four cases of disease in humans as well as infections in several animal species in New Zealand since 1931 (Table 1.4). These findings of *T. spiralis* throughout the country have created an awareness of the risk of trichinellosis from New Zealand pigs.

The four human cases were traced to the consumption of pork produced in ‘backyard’ production systems. These are typically small scale farms, quite separate to commercial enterprises. Currently, porcine abattoirs routinely sample 600 culled breeding sows annually to determine and monitor an annual prevalence of under 0.5% (with a 95% confidence interval) in pigs from commercial herds in New Zealand (Clear and Morris 2004). Testing over the past 25 years has not detected evidence of *T. spiralis* infection in any commercially raised pigs (Table 1.5). Nevertheless, New Zealand is considered endemic for the parasite, despite the national rarity of trichinellosis cases, due to 27 cases of trichinellosis in pigs from backyard production systems. Countries where no indigenous cases of trichinellosis have occurred, such as Australia, are not considered endemic for the parasite (Obendorf 1990; Pozio and Zarlenga 2005).

The most recent case of trichinellosis in New Zealand was in 2004 when an infected horse was identified by pepsin digest during testing for export (see Table 1.6) (NZVA 2004). Prior to this was a case of human trichinellosis in 2001 in Whangamata, Coromandel. The incident resulted in two people being hospitalised from an infection contracted through consuming pork products from one infected pig. The source farm involved was reportedly poorly managed, and rodents and possums were routinely shot on the property, and then left to be scavenged by cats and pigs (Thornton and King 2004). Infected rats were found by a survey of the farm and surrounding bush two months after the initial human cases were identified. Findings of *T. spiralis* in wildlife

Table 1.3. A summary of international articles reporting the prevalence of trichinellosis in humans and pigs.

Country (Region)	Reference	Study period	Test type	Species tested	Number Tested	Number Positive	Prevalence (%)
New Zealand	Clear and Morris (2004)	1969-2003	Trichinoscopy and Pepsin Digest	Pigs	307393	0	0
	Paterson et al. (1997); Thornton and King (2004)	1931-2001	Muscle biopsy	Humans	N/A use registry of cases	4	NR
	Seddon (1967); Waddell (1969)	1949-1967	NR	Pigs	Not reported	0	NR
Australia	Waddell (1969); Obendorf (1990)	NR	Cysts in cadavers	Humans	NR	NR	NR
Canada	Gajadhar et al (1997)	1980-1995	Trichinoscopy	Pigs	553 574	3	0.00054
	Gajadhar et al (1997)	1993	NR	Human	Not reported	NR	NR
USA (national average)	Gamble and Bush (1999)	1995	Serology	Pigs	7987	NR	0.013
USA (northeastern US)	Gamble et al (1999)	1998	Serology	Pigs	2132	NR	0.47
China (Hubei)	Lui and Boireau (2002)	1997	Direct Diagnostic methods	Pigs	302 667	NR	6.76
China (Henan)	Lui and Boireau (2002)	1997	Direct Diagnostic methods	Pigs	75 821	NR	4.27
China (Nine other provinces)	Lui and Boireau (2002)	1993-1999	Direct Diagnostic methods	Pigs	81 713 989	NR	0.001-0.89
China	Lui and Boireau (2002)	1991-2001	ELISA serology	Humans	36 852	NR	5.5
Argentina (Buenos Aires)	Ortega-Pierres et al (2000)	1996	Artificial digest	Pigs	519		12.3
	Ortega-Pierres et al (2000)	1993-1999	NR	Humans	Cases registered	2814	
Bolivia (Santa Cruz, Chuquisaca)	Brown et al (1996)	1996	Serology	Pigs	1327	NR	13.4
Bolivia (Santa Cruz)	Ortega-Pierres et al (2000)	1996	ELISA Serology	Humans	234	5	3

NR= Not recorded

and in backyard piggeries have created difficulties for the development of an export market for chilled pig products from commercial piggeries.

T. spiralis has been found in New Zealand, and as a consequence, the country must annually test a sample of domestic pigs at slaughter and all pigs designated as pork products for export (NZPIB 2003; Clear and Morris 2004). The current testing of 600 domestic chopper¹ pigs from commercial piggeries has not resulted in detection of a positive sample in 20 years of testing. This situation suggests two potential issues. First, the current amount of testing is inadequate to detect the infrequent positive carcasses that exist or second, that the commercial pig population destined for export is truly negative for *T. spiralis*.

This raises the suggestion that government testing could be more effectively used to address the problem of *T. spiralis* in New Zealand. Useful changes to this testing program could involve carrying out epidemiological studies on populations that would give a more accurate assessment of where problems with *T. spiralis* infection lie in the country (Gajadhar and Gamble 2000; Pozio and Zarlenga 2005). The current compulsory testing of all pork exports, even goods produced on piggeries with high health standards, has created problems for growing a competitive export market (Gajadhar, Bisailon et al. 1997; USDA 2003).

¹ Chopper pigs are mature pigs that have been culled from the breeding herd. They are considered to be good indicators of the prevalence of *T. spiralis* as they are older and so have had more time to contract infection were it present.

Table 1.4. Natural *T. spiralis* infections between 1931 and 2005 identified in a range of New Zealand species from outbreaks and surveys.

Natural Infections								
Year	Location	Species involved	no. tested	no. positive	Prevalence (%)	Test method	Reference	
1931	Wellington	human	-	1	-	clinical diagnoses	(Cairns 1966)	
		pigs	20000	0	0	squash preparation		
1950		pig	1291	0	0	rat feeding technique	(Mason 1978)	
1964	Auckland	human	-	1	-	-	(Cairns 1966)	
1965	North Island survey	pig	8696	4	0.005%	pepsin digest	(Liberona and MacDiarmid 1988)	
	Auckland	rat	1433	5	0.35%	pepsin digest		
	Auckland	cat	28	2	7%	pepsin digest		
	Auckland	mice	23	0	0	pepsin digest		
	Auckland	possums	2	0	0	pepsin digest		
	Auckland	ferrets	2	0	0	pepsin digest		
1965	Feilding rubbish tip	rat	24	2	8.3%		(Liberona and MacDiarmid 1988)	
		rat	4	1				
1968	Feilding rubbish tip	rat	181	11	6%		(Kapel 2000; Julian 2002)	
1968	Burnside, (Otago)	pig		1		trichinoscope	(Liberona and MacDiarmid 1988) (Carter and Cordes 1980)	
	Burnside, (Otago)	cat	~	4				
	Burnside, (Otago)	rat	~	0				
1973	Burnside, (Otago)	pig		1				
1974	Burnside, (Otago)	pig ^a		1				
1980	Waikato	rat	160	0	0	-	(Buncic 1997; Pozio and Zarlenga 2005)	
1997	Rotorua	pig ^b	31	4	12.9%	pepsin digest	(Thornton and King 2004)	
		rats	9	0		pepsin digest		
2001	Whangamata	human		2		pepsin digest	(Thornton and King 2004)	
		FarmA	pig	31	16	51.6%		pepsin digest
			cat	5	4	80%		pepsin digest
			rat	22	7	31.8%		pepsin digest
			possum	9	0	0		pepsin digest
			hedgehog	1	0	0		pepsin digest
		FarmD	pig	5	0	0		pepsin digest
			pig	1	0	0		pepsin digest
pig	1		0	0	pepsin digest			
FarmE	pig	1	0	0	pepsin digest			
2003	National survey	rats	398	0	0	pepsin digest	(Richardson, Unpublished data)	
		cats	12	0	0	pepsin digest		
		stoats	40	0	0	pepsin digest		
		weasels	5	0	0	pepsin digest		
2004	Routine Surveillance	horse	>53,000	1	0.001%	pepsin digest	(New Zealand Veterinary Association 2004)	

^aAll pigs on the farm were subsequently slaughtered and tested up till 1982^bHowever as some of these pigs were juveniles the prevalence was taken from just the adult sow population = 4/9 = 0.44

Table 1.5. *T. spiralis* infections identified in New Zealand pigs from routine testing for the domestic and export market.

Routine testing by pepsin digest:					
Year	Number examined	Species	Number positive	Source	
1983	117	Pig	0	(MAF surveillance data, 2004)	
1984	327	Pig	0	unpublished	
1985	329	Pig	0		
1986	310	Pig	0		
1987	361	Pig	0		
1988	312	Pig	0		
1989	284	Pig	0		
1990	291	Pig	0		
1991	244	Pig	0		
1992	238	Pig	0		
1993	255	Pig	0		
1995/96	507	Pig	0		
1996/97	533	Pig	0		
1997/98	517	Pig	0		
1998/99	463	Pig	0		
1999/00	473	Pig	0		
2000/01	615	Pig	0		
2001/02	623	Pig	0		
2002/03	594	Pig	0		

Table 1.6 Results of pepsin digest testing for *T. spiralis* in exported meat from New Zealand.

Testing for Export					
Year	Number examined	Species	Number positive	Source	
<2004	8000+	Pig	0	(Clear and Morris 2004)	
<2004	>53,000	Horse	1	(New Zealand Veterinary Association 2004)	

1.5 Indicator species for *T. spiralis* in the environment

T. spiralis may be found in a wide range of mammalian species, although the parasite is particularly well adapted to omnivorous hosts (e.g. the pig), and synanthropic animals (e.g. Norway rat). Indicator species can be used to identify the presence of *T. spiralis* in the environment (Nockler, Pozio et al. 2000). The prevalence of *T. spiralis* in the environment may be used to gauge the risk of trichinellosis infection for pigs, as pigs are typical hosts of this parasite and a human food source and therefore infected pigs are a risk for humans. Indicator species are principally medium-sized carnivores such as cats and foxes, or synanthropic omnivores such as rats.

Rats are considered important vectors of *Trichinella* to pigs (Schad, Duffy et al. 1987; Liberona and MacDiarmid 1988; Pozio 2001; Julian 2002). This is due to findings that *T. spiralis* can be maintained in a rat population where sources of re-

infection are absent (Leiby, Duffy et al. 1990), and that uninfected pigs rapidly become infected in the presence of infected rats (Schad, Duffy et al. 1987). Small carnivores such as cats and foxes have also been recognised as good indicators of *Trichinella* infection in the environment (Kapel 2000; Murrell and Pozio 2000). Small carnivores such as these are significant hosts for most *Trichinella* species because the biology and eating habits of carnivores provide good opportunities for the *Trichinella* lifecycle to continue.

Throughout Europe, surveys of foxes have been used to determine the prevalence of *Trichinella* species in the area. Foxes have been found to be good indicators of infection in sylvatic environments, probably due to being opportunistic feeders, which makes them useful in epidemiological surveys (Ortga-Pierres, Arriaga et al. 2000). In Denmark, 3133 red foxes (*Vulpes vulpes*) were examined between 1995 and 1998 for *Trichinella*. The apparent prevalence in these foxes was 0.1% (Enemark, Bjorn et al. 2000). Similarly, 7103 foxes were examined in Brandenburg, Germany from 1993 to 1995 and showed a prevalence of 0.07% for *T. spiralis* (Wacker, Rodriguez et al. 1999).

Dogs have also been used as an indicator species for *T. spiralis* in epidemiological studies. In Macedonia in northern Greece, 1000 dogs were examined serologically for *T. spiralis* giving a prevalence of 4.3% (Frydas, Alexakias et al. 1995). This study concluded that dogs acted as a reservoir for *T. spiralis* in Greece. A similar study carried out in Finland found 8.7% of 709 dogs positive for detectable *Trichinella* antibodies (Oivanen, Nareaho et al. 2005).

In the USA, stoats (*Mustela erminea*) were found to be infected with *T. spiralis* (Hoberg, Aubry et al. 1990). Stoats were first brought out to New Zealand in 1885 from England for the purpose of rabbit control, and have since become established throughout the country (King 1990). As stoats are widespread in New Zealand, and have the potential to carry *T. spiralis*, they may be useful as indicator carnivores for New Zealand studies on the epidemiology of *T. spiralis*.

Overall, testing medium sized carnivores for surveillance purposes appears to provide useful indicators of the prevalence of infection in the region of interest. Studies in Mexico and in New Zealand have found very high levels of infection by *T. spiralis* in cats from areas where human trichinellosis has occurred, indicating that they are also useful indicator species (Ortga-Pierres, Arriaga et al. 2000; Thornton and King 2004).

In Mexico City, between 1952 and 1997, there were 164 diagnosed cases of *Trichinella* in humans (including one death) and a very high prevalence identified in pigs. During this period, multiple surveys for *T. spiralis* were carried out in the affected areas. Prevalence ranged at around 15.0% in cats and 0.9% in rats for a similar area (Ortga-Pierres, Arriaga et al. 2000). This result indicated a vast difference in the prevalence of infection between the two species, where cats appeared to give a higher and potentially more accurate indication of prevalence given the levels of infection in pigs and humans in the area. At the location of a human trichinellosis outbreak in New Zealand the prevalence in the local rats and cats was found to be 32% (n=22) and 80% (n=5) respectively (Thornton and King 2004).

1.5.1 Surveys on *T. spiralis* in Rats

Rats are considered to have a vital role in the maintenance of infection in the domestic environment (Schad, Duffy et al. 1987; Leiby, Duffy et al. 1990; Murrell and Pozio 2000). Nevertheless, current literature on the ecology of *Trichinella*, case reports of outbreaks worldwide and surveys involving rats, suggest that rats may not accurately reflect the presence of *T. spiralis* in the environment and have a different role in the transmission of *T. spiralis* than previously thought (Pozio 2000; Pozio 2001; Stojcevic, Zivcicjak et al. 2004). This may be because rats eat smaller portions of food, or that *T. spiralis* does not persist in omnivores as well as carnivores (Kapel 2000).

An investigation in northern Thailand following an outbreak in 1981 that involved 177 patients and caused 13 deaths, found that all rats tested were negative, but positives were found in cats, dogs and pigs (Takahashi, Mingyuan et al. 2000). It was unclear which detection method was used. Similarly, studies on rats in the State of Mexico, where a high incidence for trichinellosis has been recorded in humans and pigs, found no positives from a pepsin digest of 120 rats collected from that area (Ayala Bello 1995; Ortga-Pierres, Arriaga et al. 2000). In these studies rats clearly did not represent the prevalence of the parasite in the environment.

In Italy, between 1985 and 1995 a wide range of animal species that were potential *Trichinella* hosts were examined by pepsin digest. The study found five out of 267 (3.2%) brown rats to have *Trichinella* in an area where sylvatic trichinellosis was endemic. The rats tested were collected from a rubbish dump that was used to dispose of fox carcasses where 25% of foxes were positive for *Trichinella* (Pozio, La Rosa et al.

1996). This suggests poor transmission to the rats from infected carcasses, as the prevalence in rats was very low compared to the infection rate noted in foxes.

In the 2001 case in New Zealand, rats were not tested until two months after the infections occurred. *Trichinella* moults from an L1 to an L4 in 2-6 days. After reproduction, numerous larvae are in the blood stream from 8-25 days post infection, and become encysted by about three months (Corwin 1999). The time interval until testing could have allowed rats to contract infection from infected pigs on the farm, rather than the other way round. However, the infection rate found in the rats sampled at the case site was similar (32% (Thornton and King 2004)) to the rate of infection found in a rat population known to be cycling *T. spiralis* (42% (Leiby, Duffy et al. 1990)).

According to Pozio (2000), rats are considered to be victims of *T. spiralis* rather than hosts, but will act as vectors of the disease if in contact with reservoir species such as red foxes, wolves, domestic pigs or wild pigs. This is supported by Kociecka (2003) who states that infected rats are only found where there is widespread infection amongst pigs or other domestic or sylvatic animals. They suggest that infection cannot be maintained naturally in a rat population for long periods of time.

1.5.2 *T. spiralis* in *Rattus norvegicus*

Kapel (1998) found that different host species, even when closely related, differ in their susceptibility to infection by *Trichinella*. Rats appear to follow this pattern, as *T. spiralis* is readily recorded in the Norway rat (*Rattus norvegicus*), but although *T. britovi* has been found in ship rats (*Rattus rattus*) no natural infections of *T. spiralis* have been found in ship rats or house mice (*Mus musculus*) (Leiby, Duffy et al. 1990; Pozio, La Rosa et al. 1996; Malakauskas, Kapel et al. 2001; Stojcevic, Zivicnjak et al. 2004; Pozio 2005).

In spite of the poor detection levels found in surveys, *T. spiralis* has been found to establish infections in Norway rats (Pozio 2005). Studies on infectivity and persistence of *T. spiralis* found rats given an initial inoculation of 2000 larvae established an infection level of 2,659-3,688 larvae/g in 150-200 g laboratory-bred rats. This high level of infection persisted until the study ended at 40 weeks (Malakauskas, Kapel et al. 2001). *T. spiralis* has been found to be infective in a rat for some time after death. In a feed trial, 24 rats were each infected with 300 larvae before being killed and placed in

different feed types or feeding situations. The infected dead rats were placed in silage, milled barley, propionic acid-preserved feed, and also simulated pasture conditions for 6 weeks. In all four conditions, larvae were still viable in the feed after 2 weeks but only parasites in the propionic acid-fermented feed were viable after 4 weeks, and no infective parasites were found by 6 weeks (Oivanen, Mikkonen et al. 2002). These studies give strong evidence that Norway rats are suitable hosts to transmit *T. spiralis* infection. Rats may be uncertain carriers of *Trichinella*, but certainly have a role in perpetuating and spreading the cycle of trichinellosis infection in pigs.

1.5.3 Potential hosts for *T. spiralis* in New Zealand

New Zealand has comparatively few mammalian carnivores or omnivores that could act as reservoirs for *T. spiralis* (King 1990). Potential wildlife hosts are cats, mustelids, possums, Norway rats and wild pigs. Norway rats are considered indicators for the presence of *T. spiralis* infection in New Zealand as they have been found to be infected at sites where infection has also been identified in pigs (Cairns 1966; Mason 1978; Liberona and MacDiarmid 1988; Julian 2002). However, studies in New Zealand, to date, have not differentiated between species of rats when testing for *Trichinella* infections. An outbreak of *T. spiralis* in Whangamata, New Zealand, where several potential indicator species were tested, showed that cats had a very high (80%) prevalence of infection compared to the other species (see Table 1.4. Natural *T. spiralis* infections between 1931 and 2005 identified in a range of New Zealand species from outbreaks and surveys.). Recently, *T. spiralis* was detected during routine sampling in a horse carcass destined for export but the source of this infection was not determined (New Zealand Veterinary Association 2004). No positive results have been found for *T. spiralis* in feral pigs in New Zealand using pepsin digest testing. Game packing houses tested 17,500 feral pigs from 1990 to 2002 for *T. spiralis*. Currently no feral meat is exported and only feral pigs over 68kg are tested for the local market (Clear and Morris 2004).

Although experimental infections of *T. spiralis* have been established in mice, naturally derived infections have not been identified in these small rodents (see section 1.6.2).

1.5.4 Effects of rodent control on trichinellosis in piggeries

The role played by rats in the transmission of trichinellosis to pigs has been a topic of debate for many years and definitive conclusions have yet to be reached. In spite of the ambiguity around the importance of Norway rats in the *T. spiralis* transmission cycle, it has been shown that the transmission of trichinellosis can be stopped with the introduction of rodent and wildlife control measures in the pigsty and feed rooms (Davies, Morrow et al. 1998; Gamble and Bush 1999; Pozio 2001; Kijlstra, Eissen et al. 2004). Studies by Leiby et al. (1990) clearly demonstrated the transmission of *T. spiralis* within and between rats and pigs through cannibalism of the carcasses of either species.

1.6 Rodents in New Zealand

1.6.1 Rats in New Zealand

In New Zealand, rats are a serious pest and vector for disease in agricultural and industrial sectors as well as in conservation (Moors 1990). Rats in New Zealand have been found to carry leptospirosis, salmonellosis, toxoplasmosis, *Sarcocystis* sp., erysipelas, *Giardia intestinalis*, and trichinellosis (Carter and Cordes 1980; King 1990; Marino, Brown et al. 1992; Gill 1995). There are two species of rat present in New Zealand of agricultural concern, the ship rat and the Norway rat.

These two species differ in several aspects of their physical and behavioural characteristics (Table 1.7). Behavioural and identification differences are described here because they are important in relation to baiting, as baits need to be placed according to the habitat preferences of the different species to be effective.

Table 1.7. Differentiating characteristics between rat species in piggeries (Innes 1990; Moors 1990).

Feature	Norway Rats	Ship rats
Morphology	Stout body, small ears, heavy tail (shorter than head and body)	Rounded skull shape, large thin ears, tail longer than head and body
Behaviour	Commonly burrows, and will swim readily	Readily climbs and inhabits areas above the ground, rarely burrows or swims
Marking	Grease marks on ground	Grease marks on pipes and beams
Weight	Average 150-300 g (max. in wild <400 g)	Males (av. 185 g) and Females (av. 163 g)

The first of these species to be identified in New Zealand was the Norway rat, recognised around 1772 (Moors 1990). Both species are now well established. The ship rat is widely spread throughout New Zealand in both forest and commensal habitats created by human activities. In comparison to the ship rat, the Norway rat is principally found only in commensal habitats (Innes 1990; Moors 1990). This successful establishment of rodents in New Zealand has resulted in widespread damage to New Zealand's native flora and fauna, particularly to birds, as rodents compete for food resources and may prey on eggs and chicks. This has made rodent eradication a high priority for conservationists, resulting in many trials on rat control in different areas of the country (Taylor and Thomas 1993; James and Clout 1996; Thorsen, Shorten et al. 2000).

Moors (1990) found that population numbers of Norway rats in New Zealand fluctuate over the year, with numbers lowest in spring and highest over autumn and early winter due to an increase in numbers of juveniles at that time. However, Innes et al. (2001) found pregnant Norway rats in every season in a study in Pureora forest park, suggesting a lack of seasonal breeding in some Norway populations. The length of gestation in the Norway rat ranges from 21-24 days, and litter size averages 6-8 kits. The young are weaned at about 28 days, but time until sexual maturity depends on whether the rat is born early or late in the breeding season (Moors 1990). Rats born early in the breeding season will mature by the end of the season, where as rats born later in the breeding season, tend to winter over as juveniles and reach sexual maturity at the beginning of the next breeding season.

Ship rats have a 6-8 month breeding season in New Zealand over the summer months. Sexual maturity is reached at 3-4 months. Young ship rats in Pureora Forest Park exhibited the pattern of low population numbers in spring, with numbers peaking in autumn until early winter due to the summer and autumn breeding period (Innes, King et al. 2001). The gestation period of the ship rat in New Zealand is 20-22 days and resultant 3-10 pups are weaned at about 21-28 days (Innes 1990). This means that two new generations are usually possible in a year. Male ship rats live for about 11 months compared to female ship rats that live for up to 17 months. However, this life span is about three times longer when kept in captivity (Long 2003). Long (2003) states that the Norway rat and the ship rat both appear to move similar distances from the nest

when foraging. On average, this is up to 200 m, but this can be as little as 22-46 m or up to several kilometres (Long 2003; Leung and Clark 2005).

1.6.2 Mice in New Zealand

The role of the house mouse (*Mus musculus*) for transmitting zoonoses in nature is unclear and overall it appears to be very minor (Blackwell 1979). Mice were first recognised in New Zealand in 1824 after a ship wreck (McNab, 1907 cited in (Murphy and Pickard 1990)). Commonly, mice have been implicated with the spread of yersiniosis, salmonellosis, and leptospirosis, however these claims have not been substantiated in New Zealand (Tannock, McInnes et al. 1971; Bolt and Marshall 1995; Cork, Marshall et al. 1995). *Giardia intestinalis* has been identified in house mice in New Zealand, however it is unsure as to whether this strain can infect humans (Marino, Brown et al. 1992).

Although mice may not become infected with many diseases, they still may spread disease to pigs through mechanical transmission via excreta, secretions and carcasses, which effectively compromises the piggery's herd health and food safety (Endepols, Klemann et al. 2003). Mouse activity also causes structural damage to buildings and creates costs due to increased feed spoilage and wiring maintenance and insulation problems (Leung and Clark 2005).

Seasonal breeding is also evident in mice, as fertility in female mice appears to decline over the winter months. Litter size appears to range from 2-12, and litters can be produced every 20-30 days (Murphy and Pickard 1990). The distance that the mice travel from their nest in normal daily activities depends on the environment. Apparently mice living indoors travel smaller distances (3.8 - 6.0 m) compared to mice living outdoors (average 274 m), this could be the result of food sources being closer in the indoor situation (Fitzgerald, Karl et al. 1981; Long 2003).

1.7 Rats in New Zealand piggeries

Both ship rats and Norway rats have been found in New Zealand piggeries (Richardson, unpublished data). As discussed in section 1.5.2, only Norway rats are associated with carrying the parasite (Leiby, Duffy et al. 1990; Pozio, La Rosa et al. 1996; Malakauskas, Kapel et al. 2001; Stojcevic, Zivicnjak et al. 2004; Pozio 2005). This is important as this host differentiation suggests that in New Zealand ship rats are not a risk to pork production as vectors or reservoirs of *T. spiralis*.

1.7.1 Rat behaviour in Piggeries

Behaviour may also affect rodent distributions in piggeries. Taylor (1978; cited in (King 1990)) found that on small offshore islands, competitive exclusion affected the distribution of rodent species. In particular, ship rats and house mice were more likely to be present when Norway rats were absent. Norway rats appeared to be able to prevent the colonisation of house mice on islands. In an Australian eradication study involving a piggery and nearby stables, mice were only detected by tracking plates once ship rats were eradicated (Leung and Clark 2005).

Movements of rats onto and around piggeries appear to be affected by the size of the rat population present. Population numbers affect the likelihood of ‘new’ rats entering the population, because in smaller colonies individuals are recognized by scent and unrecognised individuals are aggressively repelled (King 1990), but in higher density populations individuals are more readily accepted into an area.

Research by Calhoun (1963) showed rats to be defensive over territories and oestrus females, but only marginally aggressive or protective over food in an environment with an almost continuous supply of food. As this is the expected situation in many piggeries, it may be that if the rats do not guard food they probably do not guard bait either, and the whole population would have exposure to the poison. This is contrary to the situation in the bush as mature rats will guard food sources and juveniles and subordinates are unlikely to gain access to the bait till the dominant animal falls sick.

1.8 Rodent control in piggeries

Duplantler (1999) identified the successful colonisation of all available habitats by rats as the principle difficulty with rodent control. There is far less research in the area of rodent control for agricultural units in New Zealand than there is for conservation. Innes (1995) stated that long term eradication of ship rats on a large-scale, was not achieved in nine control efforts in areas of New Zealand forest. This type of situation where reinvasion is highly possible from surrounding areas is more representative of a piggery than island control studies. Intensive farming environments can often provide almost unlimited amounts of food, water, warmth, space, as well as predator-free shelter which can allow unusually high numbers of rodents to build up (Corrigan 2001). Previous studies have shown that rodent control must be ongoing and carefully planned

as rodents are adaptable and reinvasion is common where baiting has removed a resident population (Innes, Warburton et al. 1995).

Corrigan (2001) recommended a stepwise approach to rodent control that included sanitation of buildings, which refers to keeping buildings in good repair and keeping the farm clear of rubbish, over-grown vegetation, and unused equipment. Further to this, buildings should be constructed in a rodent-proof manner. This requires minimising entry points to buildings by having well-fitting doors and windows, and filling in gaps from building materials such as uncovered ends of corrugated iron. These previous two measures are primarily preventative, and in situations where the rodent population has already built up it is important to reduce the rodent population. This is most commonly achieved using poison baits. In order for a programme to be effective, it must be regularly evaluated to assess that it is working.

Attention needs to be paid to dietary preferences, potential neo-phobia (fear of new objects), social interactions, and habitat structure as these affect exposure to bait and bait consumption (Pelz and Klemann 2004). Differences in the distance travelled by an individual are related to food supply and affect how likely the animal is to encounter bait. If animals do not travel far from their nest site, bait stations must be distributed more frequently to increase the likelihood of being inside each animal's home range.

Points to consider (Taylor and Thomas 1993; Corrigan 2001) when using bait, are that bait must be placed:

- In areas where rats readily come into contact with it such as high activity areas
- Closer to nesting sites than other available feed sources
- Within each potential home range of the target species

1.8.1 Baits and bait placement

Over the last 45 years, positive steps have been made in the fields of rodent control for conservation in New Zealand. Between 1974 and 1995, Thomas and Taylor developed a very successful and practicable method for ground-based rodent eradication on islands (Thomas and Taylor 2001). They developed a system based on known rat behaviours to dispense second generation anti-coagulant baits throughout the island in a way that minimised exposure to non target species, and assisted monitoring the progress of the eradication campaign. They used “Talon WB 50” (Brodifacoum, Crop Care

Holdings Ltd.) baits in either 65 mm or 100 mm diameter ‘Novacoil’ plastic drainage pipe to eradicate all three rodent pest species (Ship rat, Norway rat, and house mouse) from different New Zealand islands. The largest of these was 1970 ha Kapiti Island in 1996. Thomas and Taylor (2001) found that using a spacing of 50 m for bait stations was effective for ship rats and house mice eradication, and a spacing of up to 100 m were effective in eradicating Norway rats.

Anticoagulant rodenticides are a commonly used poison for controlling rodent populations. Five different types of commercial anticoagulants are registered for rodent control in New Zealand (Table 1.8). All five toxins act to inhibit the formation of prothrombin and increase the permeability and fragility of the capillaries, causing internal bleeding. The liver is the main organ of storage and accumulation once the toxic compound has been absorbed through the skin, the digestive system, or the respiratory system. The size of the lethal dose depends on the species, weight and level of tolerance to the toxin used. In addition to bait avoidance, some individual animals appear to have a naturally higher tolerance to the anticoagulant baits than others and are not adversely affected by high levels of toxin in their system (Cowan, Dunsford et al. 1995; Innes, Warburton et al. 1995; Heiberg, Leirs et al. 2003).

Table 1.8. A summary from the Department of Conservation of products registered for use as of 2000 for rodent control in New Zealand (O'Connor and Eason 2000).

Toxicant	Bait type	Product Name	Distributor
Brodifacoum ^b	Pellets, wax pellets, and wax block	Pestoff® Rodent bait	Animal Control Products
		Pestoff® Rodent block	Animal Control Products
	Pellets, wax pellets, and wax ‘eggs’	Talon® 20P	Crop Care Holdings Ltd.
		Talon® 50WB	Crop Care Holdings Ltd.
Bromodiolone ^b	Extruded block	Contraç®	Pest Management Services
	Wax pellets	Ridrat®	Rentokil
	Wax pellets	Supersqueak®	Rentokil
Coumatetralyl ^a	Bait block	No Rats and Mice®	Kiwicare Corporation
	Powder and wax block	Racumin®	Bayer-AG
Diphacinone ^a	Extruded block	Ditrac®	Pest Management Services
	Liquid	Liquatox®	Pest Management Services
Flocoumaten ^b	Waxed wheat	Storm®	Cyanmid NZ Ltd

^a First generation anticoagulant: metabolised by animal faster, so requires higher intake (multi-feed bait) to cause death, however is a lower risk in causing secondary poisoning (O'Connor and Eason 2000).

^b Second generation anticoagulant: more toxic than first generation anticoagulant, so requires a relatively lower intake (single-feed bait) to cause death, however this creates a higher risk for causing secondary poisoning in non-target species (Cairns 1966).

The active ingredient of the bait used in the experiment reported in Chapter 4 was bromadiolone. The lethal dose of bromadiolone for 50% of a rat population (LD_{50}) is 1.125 mg/kg, and similarly the LD_{50} for mice is 1.75 mg/kg (Bell Laboratories 2003). Mice only eat ~5 g of food a day (Ward 1981) compared to Norway rats which eat approximately 15-30 g of food/day depending on their body weight (King 1990). A 28 g Contrac® block has 1.4 mg of active ingredient. The LD_{50} for a 20 g mouse² is 0.035 mg of bromadiolone. So 50% of mice² would only need to eat 0.7 g of bait to eat a lethal dose. Given that average food intake per day for mice is ~5 g this would only require that the mouse ate ~14% of its daily intake in bait. Similarly, the average amount of bait consumption per rat to kill 50% of the population is 5 g of Contrac® bait³. This would require that bait made up 25% of the rats' daily food intake³. Further to this, at a LD_{100} of 50 mg/kg a 200 g rat would need 10 mg of bromadiolone, or 7.2 blocks of bait to consume a lethal dose. This shows that there is a wide range in the amount of bait required to kill a rat, given the physiological tolerances of individual rats and also ranges in weight and food preferences. The absolute lethal dose for mice was unavailable for comparison.

1.8.2 Monitoring Rodent Populations

Measuring relative densities of populations rather than absolute abundance is a more efficient means of estimating population sizes as assessing relative densities does not require all individuals be located and identified (Blackwell, Potter et al. 2002). Rodents have nocturnal habits and are not always obvious through mere observation. Consequently, it is important to have a way of assessing the progress of baiting and the post-baiting efficacy of the programme. King and Edger (1977) assert that footprint tunnels can provide an efficient means of detecting small numbers of rodents. Later studies suggest the use of at least two relative density indices to estimate population sizes (Innes, Warburton et al. 1995; Blackwell, Potter et al. 2002). However, tracking tunnels have been widely used in New Zealand to assess the effects of poison baiting in many conservation sites throughout the country (Innes, Warburton et al. 1995; Gilles and Williams 2000; Thomas and Taylor 2001).

Tracking tunnels have been used extensively in large scale poisoning operations to estimate rat and mouse populations pre- and post-baiting (Innes, Warburton et al. 1995).

² Representative of the average body weight for a mouse.

³ Calculated for an average weight of 200 g.

These tunnels can be used to give a measure of abundance, where tracking rates of 12-43% were reported as moderate abundance, while tracking rates of only 0-3% were reported as rare (Innes, Brown et al. 1996). Tracking plates, similar to tracking tunnels, were used in a study of ship rats and baiting efficacy in a piggery in Queensland, Australia (Leung and Clark 2005). Leung (2005) monitored rodent levels by categorising the percentage of the plate surface that was covered with footprints into three levels of activity.

Issues with tunnels for estimating population density arise from the spatial arrangement of tunnels, baiting of tunnels, and potential aversion to new objects. Distance between tunnels affects the quality of data collected, as tunnels close together could be visited by the same rat in one night, which creates contagion or confusion of the data (Innes, Warburton et al. 1995). Non-toxic baiting of tracking tunnels is a point of contention, as the use of bait can bias results from resident populations and cause over tracking (Marten, 1972 and Innes; as cited in (King and Edger 1977)). The possibility that a new type of bait food (i.e. peanut butter) could discourage wary rats was dispelled by Inglis (1996), however, their study on wild rat responses to new foods and objects did show a very marked aversion to new objects. Their study suggested that it may take over 8 days for rats to feed from new objects, such as monitoring tunnels in the environment. An Australian study (Leung and Clark 2005) attempted to avoid this problem by using tracking plates rather than tunnels. This method appeared effective in their study, but dust could be a potential problem if using this method inside older piggeries or outside in inclement weather.

1.8.3 Secondary effects of using poison baiting to control rodent populations

There are concerns of rodents reinvading a habitat once initial rodent control has been achieved. Tunnels and trapping indices of rodent abundance in nine mainland forests during baiting efforts in these areas, showed an initial population reduction in ship rat populations but most populations recovered after 2-5 months, or one breeding season (Innes, Warburton et al. 1995). Poisoning operations on New Zealand offshore islands appeared to be effective long-term, once rodents were eradicated. This highlights the role reinvasion plays in the poor success rate of mainland baiting operations (Thomas and Taylor 2001).

Eradicating a particular target population such as rats, can result in population increases in other unwanted species. This is particularly notable in mice, where mice numbers and mouse tracking rates appear to increase substantially in areas where rats have been eradicated (Innes, Warburton et al. 1995; Dickman 2003; Leung and Clark 2005).

Further side effects of baiting in piggeries include the potential for secondary poisoning. Secondary poisoning occurs when predators and scavengers are exposed to rodenticide-contaminated animals (Brakes and Smith 2005). Although bromodiolone appears to have a lower rate of causing secondary poisoning than the other two second generation anticoagulants (brodifacoum and flocoumafen) used in New Zealand, it is still an issue when using this bait (O'Connor and Eason 2000). In particular, the issue arises on pig farms that pigs could consume poisoned rats which would result in bait residues entering the human food chain.

The maximum tolerated dose of Contrac® for a non-target animal such as a pig is ~18 x 28 g blocks per kilogram of body weight, and for a dog are ~7 x 28 g blocks per kilo. This means that an issue arises not over pigs being poisoned from anticoagulant bait but rather over the potential of residues in pork meat if a pig was to consume bait.

1.9 Analysing rodent populations over space and time

1.9.1 Logistic regression

In 1996 Langton and others used logistic regression to investigate the key factors affecting the presence of rodents in a house condition survey (Langton, Cowan et al. 2001). Regression analysis describes the relationship between an outcome and one or more explanatory factors. These 'factors' are usually referred to as variables. Logistic regression is distinguished from other regression techniques because there are only two possible outcomes (Hosmer and Lemeshow 2000). This means that the outcome data is either binary or dichotomous. The outcome variable is also called the dependent or response variable. Put simply, logistic regression is a statistical technique used to assess trends in a data set by building a model to assess how input factors are related to the output factor. Analysis of the model results looks at the significance of the effect of an input factor on an output factor whilst considering the biology of the relationships involved.

Although the outcome of a logistic regression is a simple dichotomous variable, the explanatory variables can be more diverse. The explanatory variables (also called independent or predictor variables) can contain several categories (Al-Ghamdi 2002). They are also affected by time and space so it is important that the structure of the data set is considered when analysing these variables. An underlying assumption of logistic regression analysis is that the outcome variable is independent of other observations (Panageas, Schrag et al. 2003). However, if some of the response variables are more similar to each other than to other data due to the method of collection, then the variables will in fact be clustered rather than evenly dispersed.

Clustered data occurs when test subjects are more related to some subjects than others in the pool. For example, in a study looking at genetic traits in dogs, dogs from the same litter are likely to be more genetically similar to litter mates than to dogs from another litter, so treating them all the same would create bias in the data. Clustered data also occurs when repeated measurements are taken over time. Clustering in the data must be accounted for by the method of analysis. Not accounting for clustered data causes the data to become over dispersed and increases the significance of the outcome, creating falsely significant data (Hosmer and Lemeshow 2000; Panageas, Schrag et al. 2003).

1.9.2 Geographic Information Systems

Spatial prediction techniques are useful to analyse population dynamics throughout particular habitats. Rats can be elusive, and part of sustaining long term control is to identify aspects of the environment that maintain pest populations (see section 1.8). Geographic Information Systems (GIS) can be used to assess what habitats were most likely to support Norway rats by mapping rat occurrence over a wide area with respect to features such as buildings, waterways, and vegetation (Traweger and Slota-Bachmayr 2005). Similarly the success of pest control strategies can be assessed by using GIS methods. Biological factors such as dispersal patterns, home range sizes and habitat utilisation can be graphically displayed to improve investigator understanding of the species and therefore the position and frequency of bait placements, as well as gauging the speed of recovery of pest populations after baiting efforts (Buckle, Chia et al. 1997; Fraser, Overton et al. 2003).

1.10 Risk assessment and control programs for *Trichinella*

During 1997 Switzerland used an extensive epidemiological investigation to assess the status of *Trichinella* in their domestic pig herd. No positives were found in 11 226 domestic pigs, 356 wild boars using the standard artificial digestion method or in 25 239 serum bank samples from sows. This study was used to conclude that *T. spiralis* or any other *Trichinella* does not occur in the domestic pig population in Switzerland; however *Trichinella britovi* was detected in 4 of 452 (0.9%) wild foxes (Gottstein, Pozio et al. 1997).

Recently the methodology of risk analysis (see Figure 1.2) has been employed to determine the likelihood of contracting transmissible diseases from food sources. This method involves using epidemiological data to investigate potential risks from disease.

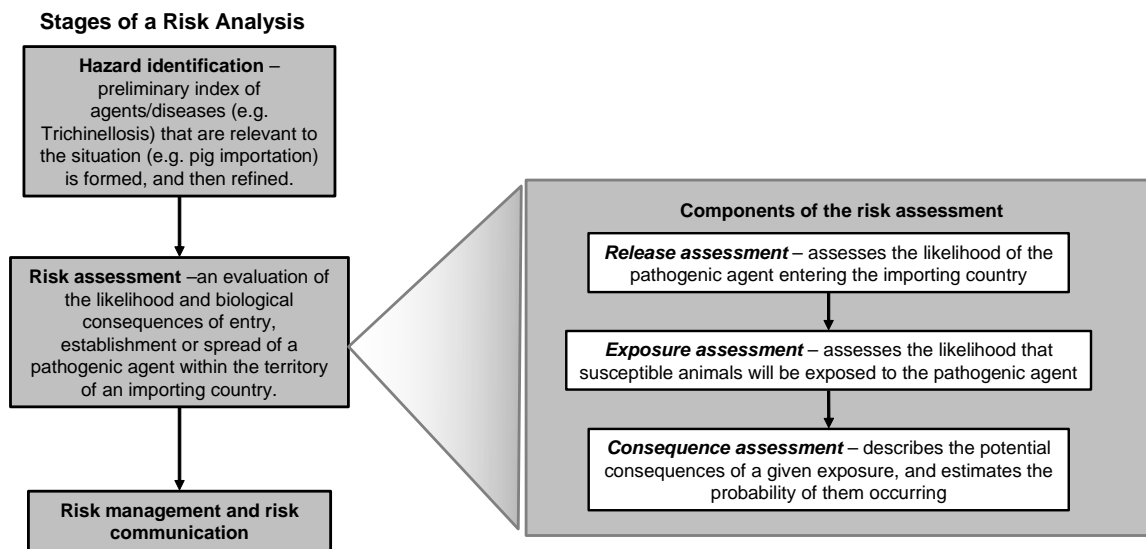


Figure 1.2 Components of a risk analysis, including the steps of the risk assessment, as described by the World Organisation for Animal Health.

1.10.1 Risk assessments for food safety

The technique of using models to assess risk has been well used by finance institutions for many years (Hartnett 2001), and more recently risk analysis has been used to provide a scientific basis for food safety risk management decisions (Foegeding 1997). Quantitative risk assessment has previously been used in food safety risk assessment for a variety of different situations. Examples of previous studies are the modelling of *Salmonella enteritidis* in pasteurized liquid eggs (Whiting 1997), the investigation of the occurrence of *Campylobacter* in chickens at the point of slaughter

(Hartnett 2001) and also for importation risk-assessment, such as for the importation of brucellosis-infected breeding cattle into Great Britain from selected European countries (Jones 2004).

An assessment of the risk to humans of infection by *T. spiralis* from pigs raised in commercial piggeries has not been carried out in New Zealand. Previous case reports and surveillance data, as well as current wildlife testing, may be utilised to build a risk assessment model. This type of model can be used to rationalise the implementation of an accreditation programme. Such a programme would allow compliant farms to document that their pigs have a negligible risk of being infected with *T. spiralis*. This would improve their potential for accessing export markets (Foegeding 1997; Lammerding and Fazil 2000; Hartnett 2001).

Hazard analysis critical control point program (HACCP)

Hazard analysis critical control point program (HACCP) is a structured approach to identify those areas within a production process that might result in unsafe food (Brooks 2000). This approach is designed to cover microbiological, physical and chemical hazards. A hazard is something that may harm the health of the consumer. It is a requirement in some countries to have a Food Safety Program (FSP) based on HACCP analysis. The use of HACCP can facilitate an exemption from food hygiene regulations because it identifies and controls all potential hazards. HACCP increases food safety, and decreases claims and costs of production which increases profit.

Seven principles of HACCP (outlined in section 1.10.2) demonstrate that potential hazards are identified and monitored at strategically placed critical control points. Food safety programs and hazard analysis are only concerned with safety issues which apply to a single product, produced in a single plant. This causes a problem when trying to apply one hazard analysis to multiple farms. In such a case good manufacturing practice rather than the HACCP program is followed. Good manufacturing practices are an industry consensus on the best way to produce a particular product. *Trichinella* certification programs, such as the one being developed by the United States Department of Agriculture, incorporates HACCP principles to minimise the risk of pigs being infected by the parasite (Anon. 2001).

1.10.2 Seven principles of HACCP

1. Identify Hazards; eliminate hazards where possible, and set up controls for those that remain.
2. Identify critical control points for hazards that remain.
3. Establish limits for critical control points. If the process exceeds the established limits at the critical control points, then the process is not in control and a potential food safety hazard exists.
4. Establish monitoring procedures to ensure critical control points are within critical limits.
5. Establish corrective actions if critical limit is exceeded.
6. Verify system is working. Examine the records of the process and institute a structured testing program to confirm that the process is working.
7. Maintain records and documentation. These records must demonstrate that the process remains under control at all times. Documentation describes the whole process and how it is controlled.
 - a. Raw material purchase
 - b. Processing steps and appropriate critical control points
 - c. Storage and delivery of the product

Records and documentation must be up to date and actually reflect the whole process.

1.11 Singaporean pork market

Singapore is a highly developed nation which relies on imported pork and pork products for its population of 4,131,200 (June, 2001). Roughly 75% of the Singaporean population is of Chinese descent, for which pork and pork products are a major part of the diet. In 2000 the retail market for pork was estimated at \$400 million, however, New Zealand has no share in this market (Agri-food 2001; Ambrose 2002). New Zealand has an international reputation for premium quality export meat and is a significant global exporter of beef and lamb; nonetheless the New Zealand pork industry has not established itself as a competitive exporter. Marketing plans are currently underway to develop New Zealand's position to market pork to Singapore (NZPIB 2004). One of the constraints to this process is the requirement of compulsory testing for *T. spiralis* of all pig carcasses, which is costly in both time and money (NZPIB 2003).

1.12 Aspects of *Trichinella* in New Zealand

This project was conceived to address concerns from importers relating to the status of *Trichinella* in New Zealand. The possibility of contracting trichinellosis from New Zealand pork products was brought to the fore in 2001 when two persons contracted trichinellosis after coming into contact with infected pork products (Thornton and King 2004). Prior to this, the most recent case of human trichinellosis occurred in 1964 (Cairns 1966). Since 1969 culled breeding pigs have been routinely tested for *T. spiralis* at slaughter in New Zealand abattoirs (Clear and Morris 2004). Moreover, localised investigations have been carried out at any time *T. spiralis* has been identified in pigs or humans (Elliot 1960; Cairns 1966; Mason 1978; Paterson, Black et al. 1997; Thornton and King 2004). However, a nationwide assessment of *Trichinella* in New Zealand has not been carried out for 38 years, and the transmission pathway for *T. spiralis* in New Zealand has not been studied (Mason 1978).

Initially this project was founded on the perception that rodents play a key role in the transmission of *T. spiralis* to pigs in piggeries. In accordance with this, the first two studies aimed to ascertain the prevalence of *T. spiralis* in wildlife, and investigate how effectively barriers to rodent activity could be achieved in piggeries. Farm management practices are considered to affect both rodent numbers and disease status in piggeries. Therefore, in addition to the first two projects, a survey was carried out in order to determine routine management practises on commercial piggeries throughout New Zealand, from which factors that may encourage or prevent *T. spiralis* could be identified. These studies still did not assess the overall risk of trichinellosis from New Zealand produced pork to the consumer. As a result, this project developed into establishing a risk model that evaluated previous data from routine testing and investigations from New Zealand, along with information about the disease from overseas, to establish the risk of trichinellosis from domestically produced pork or pork products.

Accordingly, this thesis is focused on assessing the risk of *T. spiralis* transmission into and within New Zealand piggeries as well as the risk to a consumer of contracting trichinellosis from New Zealand produced pork or pork products.

2 An investigation of selected populations of Cats, Rats, Stoats and Weasels for *Trichinella spiralis* in New Zealand Wildlife

2.1 Introduction

In New Zealand, in 2001 two people were hospitalised due to trichinellosis contracted from non-commercial pork production (Thornton and King, 2004). This incident prompted questions regarding the prevalence of *Trichinella spiralis* in New Zealand. This parasite has been periodically identified in New Zealand but is thought to be extremely rare in the environment (Gill, 1995; Clear and Morris, 2004). *T. spiralis* is a muscle parasite that causes the zoonotic List B disease, trichinellosis (World Organisation for Animal Health, 2004). The disease results from the ingestion of infective larvae in under-cooked muscle tissue. It is thought that the parasite can be carried by cats and Norway rats which then act as a source of infection to domestic pigs (Mason, 1978; Liberona and MacDiarmid, 1988). Epidemiological studies support a link between trichinellosis and swine production (Gajadhar and Gamble, 2000; Murrell and Pozio, 2000; Ortega-Pierres et al., 2000; Bowman, 2003).

The human infections in 2001 were traced to an infected pig raised in the Whangamata area and a high prevalence of infected cats (80%) and rats (32%) were found around the source farm (Thornton and King, 2004). Cases of *T. spiralis* in humans, pigs, rats, cats and a horse from different locations in New Zealand and studies of the organism in New Zealand provide only clues about the distribution of *T. spiralis* in this country. *T. spiralis* findings in New Zealand over the last 74 years are outlined in Section 1, Tables 1.4, 1.5 and 1.6 (Cairns, 1966; Paterson et al., 1997; NZVA, 2004; Thornton and King, 2004).

Rats are generally considered to carry infection when they are present in an area where *T. spiralis* is prevalent (Cairns, 1966; Mason, 1978; Schad et al., 1987; Liberona and MacDiarmid, 1988; Pozio, 2001; Julian, 2002). Rats and carnivorous mammals such as cats and mustelids can be used to ascertain the prevalence of *T. spiralis* in an

ecosystem by examining their muscle tissue for the parasite (Pozio et al., 1996; Kapel, 2000; Nockler et al., 2000; Pozio, 2000).

In New Zealand, diseases that are at a low overall prevalence such as trichinellosis, are only likely to occur at high numbers in localised areas (Enemark et al., 2000). This requires samples to be taken from a range of geographical locations. It is generally unfeasible to collect simple random samples from a broad geographical area, so sampling usually involves clustered samples randomly selected within chosen localities (Bennett et al., 1991; McDermott and Schukken, 1994; Otte and Gumm, 1997).

This study aimed to assess the distribution and prevalence of *T. spiralis* in New Zealand wildlife captured from commercial piggeries, conservation areas and landfills. It also aimed to investigate how rat species were distributed throughout these three environments.

2.2 Materials and Methods

2.2.1 **Experimental design**

The study aimed to collect three sets of 1000 rats, where each set sampled a different environmental source of rats: commercial piggeries with more than 100 sows; Department of Conservation (DoC) reserve land; and waste disposal landfills throughout New Zealand. Furthermore, cats, stoats and weasels were collected when samples became available, although these species were not killed primarily for the purpose of this study. These further species were collected due to the suspicion that *T. spiralis* is more readily detected in small carnivorous species despite previous New Zealand studies determining rats as the principle source of trichinellosis for pigs and humans. All samples were tested for the presence of *T. spiralis* larvae by a modification of the international standard pepsin digest test using a magnetic stirrer (OIE standards).

The sample size of 1000 rats was set because it allowed for prevalence to be detected down to 1% with a 95% confidence interval in each source environment investigated. It was important that the sample size allowed for the detection of a very low prevalence, as *T. spiralis* has only rarely been found in New Zealand. While the aim was to determine the distribution and prevalence of *T. spiralis* in New Zealand as a whole, logistic constraints dictated that the study concentrated on the four regions with the

greatest pork production, thus where the greatest number of susceptible individuals (pigs) were situated. These regions were Region 1- Waikato/ Coromandel area, Region 2 - Manawatu/ Taranaki area, Region 3 - Canterbury, and Region 4- Timaru/ Oamaru.

2.2.2 Data collection

2.2.2.1 Rats - Norway rats (*Rattus norvegicus*) and Ship rats (*Rattus rattus*)

Norway rats and ship rats were collected from piggeries, Department of Conservation lands and landfills.

Rat collection from piggeries

Pig farmers were contacted by mail explaining the nature of the study (see Appendix 2.2) and requesting rats killed on their piggery to be sent to Massey University. The request was followed up with phone calls and reminders during the 2002 and 2003 New Zealand Pork Industry Board seminar series. Contributing farmers were thanked by letter (see Appendix 2.3) and supplied with polystyrene insulated boxes, slicker pads (to keep sample chilled during transportation) and courier tickets. Farmers packed the killed rats and sent them via courier to Massey University in the insulated box. Rats were killed on farms by trapping, baiting and shooting. It was recommended that rats be stored in a freezer until a full box was ready to send. Rats were stored frozen at Massey University until processing.

Rat collection from Department of Conservation lands

Department of Conservation offices were contacted throughout New Zealand by phone or email and asked about current rodent control programmes in their area that may provide rats suitable for testing. Only offices with trapping programmes that recovered freshly dead rats were suitable. Rats were sent to Massey University by the same methods as for piggeries.

Rat collection from Landfills

Landfills were contacted by phone or through the city council to assess whether rats were readily available at that site. At the Palmerston North landfill snap-traps were laid out where rats had been noted by staff, and at the Feilding landfill rats were killed as they ran from the rubbish as it was being compressed. Dead rats were stored frozen until processing.

2.2.2.2 Cats (*Felis catus*)

Samples were taken from cats that had been collected from the Feilding landfill for an approved Massey University feeding trial. These cats were ethically euthanised as part of that trial. The samples were stored frozen until processed.

2.2.2.3 Stoats (*Mustela erminea*) and Weasels (*Mustela nivalis*)

The Coromandel Department of Conservation office trapped stoats and weasels, and sent them to Massey University by the same methods used for rats.

2.2.3 Sample collection

At Massey University the subjects were thawed, and the weight, species, gender, maturity and capture location recorded for each individual. Their diaphragm, masseter muscles and tongue were then removed for testing (see Figure 2.1). Carcass remains were incinerated.



Figure 2.1 Rat dissection in the post mortem room at the Institute of Veterinary, Animal and Biomedical Sciences, Massey University. The diaphragm, masseter muscles and tongue were removed and tested for *T. spiralis*.

2.2.4 Testing

The muscle samples were artificially digested and analysed for the presence of *T. spiralis* at the Institute of Veterinary, Animal and Biomedical Sciences (IVABS) Parasitology laboratory (approved by the New Zealand Food Safety Authority (NZFSA), April 2003). The testing protocol is detailed in Appendix 2.1. This protocol was a modified version of the NZFSA/MAF protocol followed by Gribbles Pathology [Detection of *T. spiralis* in bulked feral pigs or horse muscle: Export samples. (Based on MAFRA Meat Circular 93/RAM/4, 93/12/1: Technical Directives 94/189, 95/35)]. In brief, muscle samples were digested in 0.4% pepsin and 1.6% HCL solution until

complete muscle disintegration was achieved. The digested medium was sieved and larvae recovered by sedimentation.

Modifications from the NZFSA/MAF protocol related to the relatively small volume of tissue obtained from a rat compared to a horse or pig. The average amount of tissue per batch was approximately 20 g for rats, but 100 g of muscle sample was specified in the original digest test method. Therefore a 400 mL of digest fluid in a 600 mL beaker was used for digesting the rat samples rather than the recommended 2 L. Other changes included using a 300 µm aperture sieve rather than the 177 µm aperture sieve used by the Ministry of Agriculture and Forestry (MAF).

2.2.5 Test verification

The sieving and settling procedure was validated in the laboratory using formalin-preserved *T. spiralis* larvae. As no known positive meat samples were available to verify the sampling procedure.

Test verification involved two steps. First, recovery of formalin-fixed larvae from water was assessed. This was followed by the recovery of formalin-fixed larvae from a blended pepsin-digest pork solution. A pork digest mixture was made of 2 L of water, 100 g blended pork with 1% pepsin and 1% HCL. Digested pork was divided into eight replicates. In both steps, 14-17 larvae were placed in each respective water or pork digest replicate, and then the fluid was processed by sieving and sedimentation as in Appendix 2.1, steps 5-7.

2.2.6 Analytical Techniques – Sample size calculations

2.2.6.4 Clustered sample analysis

Samples were analysed separately in Microsoft Excel (Microsoft Office Excel, 2003) for piggeries, Department of Conservation lands and landfills depending on how the samples collected were dispersed. A cluster sampling analysis was undertaken to estimate the precision¹ and accuracy² of the number of samples analysed for the presence of *T. spiralis* in rats collected from geographically separate locations. The approach used by the World Health Organization (WHO) was followed to assess the precision and accuracy to which our results could be interpreted (Bennett et al., 1991).

¹ Precision refers to how closely the sample statistic predicts the true prevalence.

² Accuracy is with what level of confidence the sampling can predict the outcome.

Samples were clustered according to their collection location (e.g. each piggery or landfill). Samples within a cluster would be more similar than between clusters and analytical corrections were made to account for this. This correction factor is part of the cluster sampling analysis, and is known as the ‘design effect’. The design effect (D) is calculated using the equation below:

$$D = 1 + (b - 1)roh$$

Where b is the average number of samples per cluster and roh is the rate of homogeneity, or likely difference in prevalence between clusters. Roh differs between types of infection, such as highly contagious, or vector-borne (Otte and Gumm, 1997). Specific values of roh for *T. spiralis* were unknown, but was estimated at 0.15 based on previous studies and roh survey data for other parasites (McDermott and Schukken, 1994; Otte and Gumm, 1997). The design effect was then used to calculate the standard error (SE) which is a measure for precision of the sampling technique. This calculation is shown below:

$$SE = \sqrt{p(1 - p)D / n}$$

The value n is the total number of samples collected in all clusters, and p is the estimated prevalence. The SE is doubled to give the level of precision at the 95% confidence level. The SE is also used to derive the necessary number of clusters (c) to give an adequate sample size. This calculation is shown below:

$$c = \frac{p(1 - p)D}{SE^2 b}$$

2.2.6.5 Non-clustered sampling

Where all samples were collected from one location a simpler sample estimation analysis was used. The expected prevalence (p), desired precision (e), and desired level of confidence (z) was used to calculate the required sample size for the non-clustered samples. This calculation is shown below:

$$n = z^2 \times \frac{p \times (1 - p)}{e^2}$$

This equation was rearranged to give the level of confidence (z) at which the sampling structure can correctly predict the expected prevalence, within the specified precision.

2.2.7 Analysis of sampling technique

Piggeries: These formed 11 clusters and were analysed by cluster analysis. However, only nine were included in the cluster analysis as two of these farms did not have Norway rats. The sample collection was assessed on whether it gave sufficient precision to detect disease at 32%, which is the prevalence found in infected Norway rats living on a New Zealand non-commercial piggery in 2001 (Thornton and King, 2004).

Landfills: Only the Feilding site was analysed as at the Palmerston North site only one rat was recovered. Consequently, a non-cluster analysis was undertaken. The sample size achieved by this study was assessed on whether it was sufficient to detect *T. spiralis* at the same prevalence (6%) found at the same landfill site in 1968 (Liberona and MacDiarmid, 1988).

DoC Land: Of the three DoC locations only two of the three had Norway rats, and at both of these sites, Norway rats were in such low numbers that it was not feasible to carry out sample size analyses.

2.3 Results

2.3.1 Sample collection

Rats, cats, stoats and weasels from 16 different sites around New Zealand were tested for *T. spiralis* sampling. The location and count of animals collected for assessment are presented in Table 2.1. Rats were collected from 11 commercial piggeries, three DoC areas and two Council Landfills. DoC areas in North Canterbury and Waikato were also contacted but neither had programmes operating that involved collecting rats suitable for dissection. Cats were collected from the Feilding landfill, while stoats and weasels were collected from the Moehau Kiwi Zone, Coromandel. Ship rats were the most common species tested, closely followed by Norway rats.

Table 2.1 Details of the 16 sites around New Zealand from which rats, cats, stoats and weasels were collected and tested for *T. spiralis*.

Environment	Location	Rat (Norway)	Rat (Ship)	Cat	Stoat	Weasel	TOTAL
Landfill-1	Palmerston North	1	-	-	-	-	1
Landfill-2	Feilding	33	-	10	-	-	43
DoC area-1	Coromandel	8	53	-	40	5	106
DoC area-2	Tongariro	-	90	-	-	-	90
DoC area-3	Wanganui	2	25	-	-	-	27
Piggery- 1	Christchurch	13	-	-	-	-	13
Piggery- 2	Otorohanga	-	59	-	-	-	59
Piggery- 3	Hampden	12	-	-	-	-	12
Piggery- 4	Christchurch	8	-	-	-	-	8
Piggery- 5	Featherston	12	-	-	-	-	12
Piggery- 6	Otorohanga	16	3	-	-	-	19
Piggery- 7	Feilding	2	1	-	-	-	3
Piggery- 8	Foxton	-	11	-	-	-	11
Piggery- 9	Ohau	3	1	-	-	-	4
Piggery-10	Morrinsville	21	7	-	-	-	28
Piggery-11	Wanganui	5	1	-	-	-	6
TOTAL		136	251	10	40	5	442

Rats were found in commercial piggeries, DoC land and landfill sites. The proportion of Norway rats relative to ship rats differed between habitats (see Figure

2.2). There seemed to be a strong trend for ship rats to predominate in the DoC area collections, whereas no ship rats were found at landfill sites. There did not appear to be any real difference in the overall numbers of ship rats to Norway rats found on piggeries.

Collecting rats at landfill sites was more difficult than expected. They were present in lower numbers than expected from historical accounts. Three of the five landfills contacted in the Manawatu/ Taranaki/ Southern Waikato region did not sight rats regularly and did not believe efforts to catch rats at their sites would be successful. Modern landfill practises involve regular compression and movement of rubbish, which discourages large rat populations (Coralde, 2003). Several landfills used cats to control rats, and found this effective. Night time spotlighting at Landfill-1 for 2 hours after dusk resulted in no rats being seen, even in suspected ‘problem’ areas. However, rats were seen by workers during the day at this site.

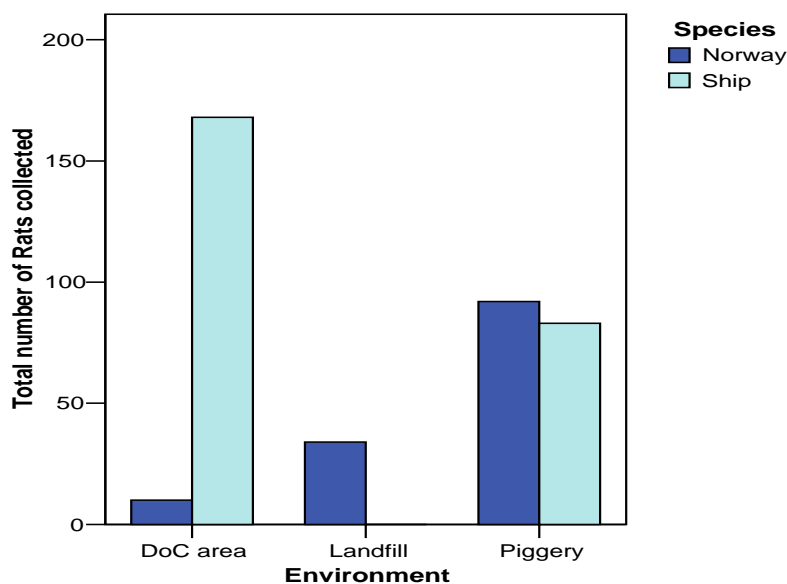


Figure 2.2. Norway and ship rats were sourced from three different environment types.

Weight (kg) was used to compare the two rat species found in the study. Although rats were collected from several different sites, Figure 2.3 shows that the weights for both populations were normally distributed (Test for non-normality was $P=0.891$, and $P=0.846$). Analysis of the two populations found a significant difference in the mean weights ($P<0.001$). Ship rat weights appeared more closely grouped around the mean

than Norway rats. This may have been a result of the different locations from which the samples were collected. Ship rats from piggeries were primarily sourced from one piggery in Otorohanga and DoC areas in Coromandel and Tongariro. Norway rats came from 11 different piggeries, landfills in Palmerston North and Feilding and DoC areas in Coromandel and Wanganui. Norway rats from landfills were approximately 100 g heavier than Norway rats from piggeries ($P < 0.001$), but there was no difference in weights of ship rats from conservation land and ship rats from piggeries ($P = 0.110$). The combined weight of an individual rat's diaphragm, masseters and tongue ranged from 1 g to 7.1 g, with a mean of 2.5 g for the first 114 rats tested. These tissue weights were not differentiated by species.

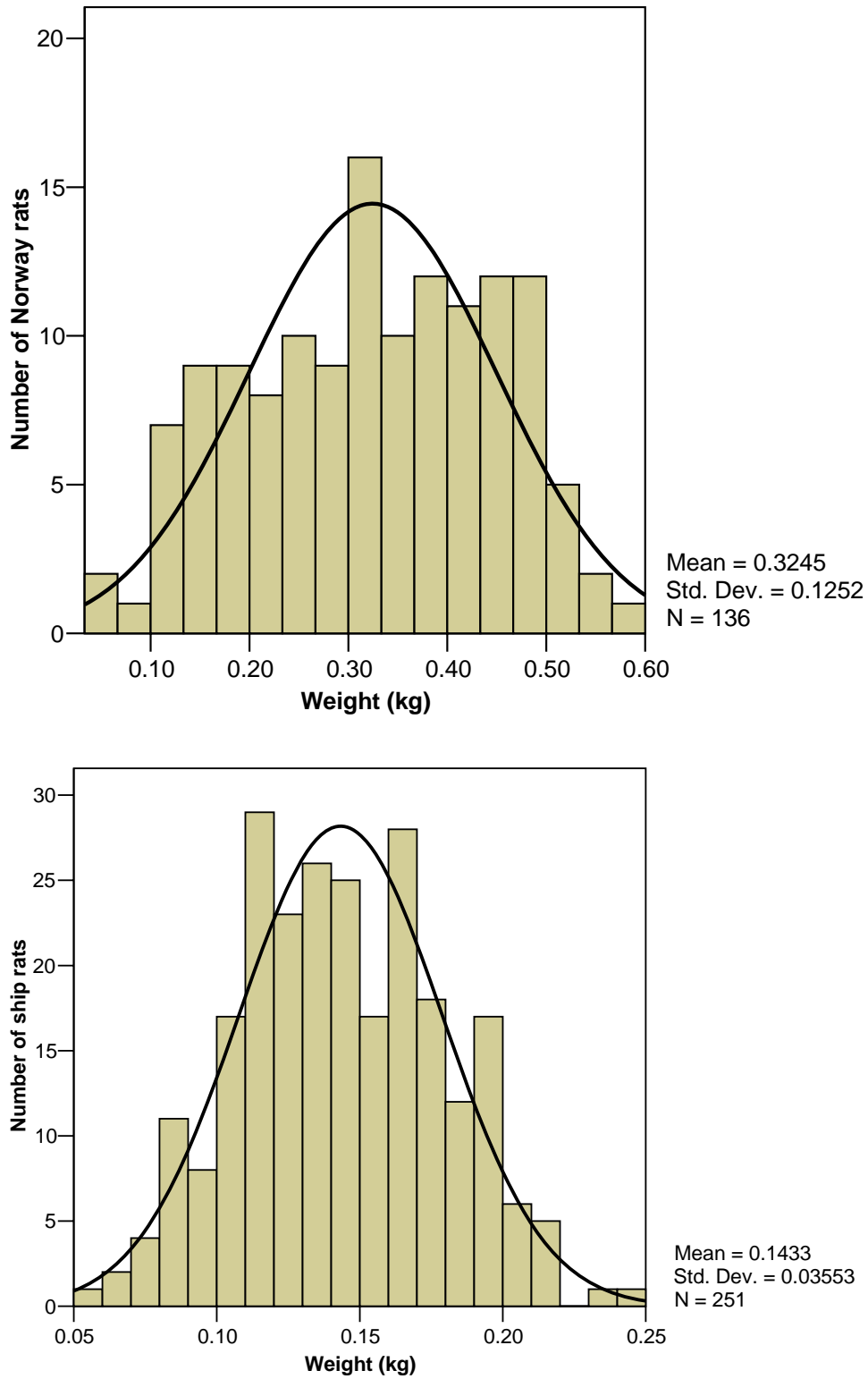


Figure 2.3. Distribution of weights of Norway rats (top) and ship rats (bottom) collected from different locations throughout New Zealand. The black line is a normal curve.

The numbers of Norway rats and ship rats sampled differed widely between the eleven commercial piggeries (Figure 2.4). On five of the 11 piggeries both species were present, however on all of these farms Norway rats were caught in higher numbers than ship rats. Of the six piggeries where only one species was identified, four of these were exclusively Norway rat populations. Piggery 2 was an exception, where a very high number of ship rats were caught.

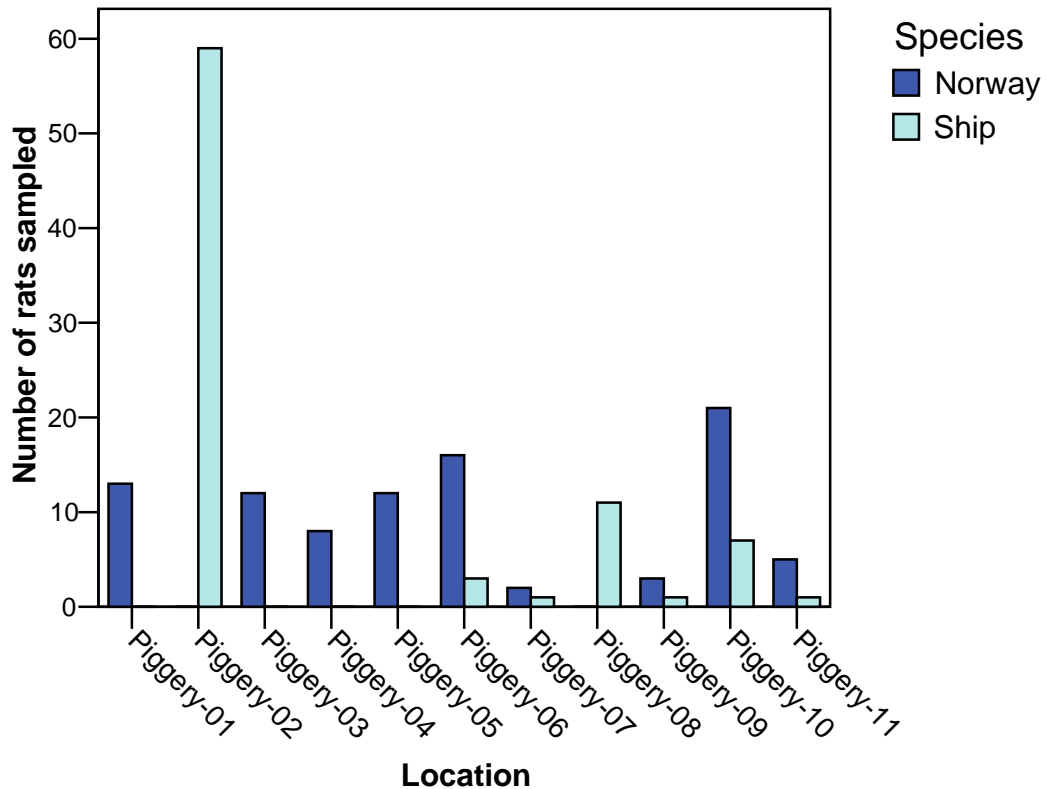


Figure 2.4. Numbers of Norway rats and ship rats collected from eleven commercial piggeries.

2.3.2 Results of sample size calculations

Piggeries: Cluster analysis of piggery samples showed that the sample collection method used had a relatively large standard error. Using this sample collection method we could be 95% certain that prevalence detected by the sampling was within +/-15% of the true prevalence. Thus, had the true prevalence over the sampled clusters been 32%, the sampling method used could have varied from 17% to 47%.

Landfills: The sample size of 33 rats from the Feilding landfill gave a 54% level of confidence that a true prevalence of 6% could be detected at a testing precision of +/- 3%.

DoC land: These were not analysed as only a small number of Norway rats were recovered from this environment.

2.3.3 Lab results

No *T. spiralis* larvae were found in the pepsin digest testing from any species of all 442 wildlife samples.

2.3.4 Test verification

Recovery rates of formalin fixed *T. spiralis* larvae from water were very high (84%) from the first 40 ml run off after sedimentation, and a further one larvae was found in the second 40 ml runoff. The same procedure applied to digested pork meat recovered on average 45% (SD = 22%) of formalin fixed larvae.

2.4 Discussion

T. spiralis was not found in any of the 442 wildlife samples collected from rats, cats stoats and weasels from 16 locations around New Zealand. This could be due to the testing and sampling process, or it may be indicative of a very low prevalence of *T. spiralis* in New Zealand.

The number of larvae in the muscle sample depends on the number of larvae ingested by the host and how successfully new-born larvae establish in the host. This is estimated by calculating the reproductive index (RCI).

$$RCI = \frac{\text{Total number of muscle larvae}}{\text{Number of viable larvae inoculated}}$$

Pozio et al. (1992) calculated that the RCI for six female 200 g rats inoculated with 2,000 larvae, was 205. By multiplying the RCI by the number of larvae inoculated, the total number of muscle larvae would have been approximately 410,000 larvae per rat. However, this does not indicate the likely number in each muscle; rather it is an estimate for the total number of larvae in the rat. *Trichinella* settle in different numbers in different muscle groups, and tend to prefer muscles more readily supplied with blood (Nockler et al., 2000).

The RCI value can be used to estimate the number of larvae produced from one infected female. The minimum larval burden in a rat from one female parasite is

approximately 205 larvae (Pozio et al., 1992). The average weight of a Norway rat found in this study was 300 g, and using an estimated percentage of meat from a rat of 30% of body weight, the average rat has 90 g of muscle. If the larvae were evenly distributed this would give 2.3 larvae/g. As larval densities of *T. spiralis* differ between muscles groups, the most heavily infected muscles are selected for detection purposes. However, as larvae are not evenly distributed it is reasonable to expect at least four larvae/g in the masseters, tongue and diaphragm of a lightly infected rat.

The pepsin digest test is sensitive to 1 larva/g when a 5 g sample of muscle is tested, or 3 larvae/g if only one gram of tissue is used (Forbes and Gajadhar, 1999; Gamble, 1999; Bessonv et al., 2003). This suggests that a 1 g sample with a larval burden of 4 larvae/g (as estimated for a minimally infected rat) should test positive using the pooled digestion method. Given that the average amount of tissue recovered in our study was 2.5 g and no samples were smaller than one gram, it is very likely that the test used in this study would have detected a positive, had there been one.

Furthermore, the validation technique found that the recovery from the settling out process was 45% (+/- 22%) after sieving and sedimentation which would allow five larvae to be recovered from a minimally infected 2.5 g sample. This indicates that infected rats would have been detected using our sieving and sedimentation methods.

The likelihood of detecting *T. spiralis* in cat and mustelid samples should be higher than that for rats. The amount of muscle collected from them is greater, providing a better chance of larvae recovery (King, 1990). Given that the same testing procedure was used, there should not be a change in test sensitivity. The minimum level of infection is not known for cats or mustelids and the reproductive capacity of *T. spiralis* varies between host species. Yet carnivores are considered the preferred host for *T. spiralis* over omnivores, with suggests that the reproductive capacity of *T. spiralis* should be higher in cats and mustelids compared to rats (Kapel, 2000).

Rats could become highly infected by scavenging parasitised carcasses. Rats and cats in the Mangakino area in 1965 were found to have up to 3,500 larvae throughout the carcass whereas more recent findings of *T. spiralis* in 1997 in several pigs found burdens of up to 92 larvae/g. These infection levels could lead to a high number of viable larvae being eaten (Cairns, 1966; Paterson et al., 1997). However, Norway rats

eat up to 10% of their body weight per day, thus only 20-30 g of food and probably eat from more than one food source over a day (Moors, 1990; Pozio, 2005).

Larval burden in different muscles was investigated in five month-old wistar rats inoculated with 500 encysted *T. spiralis* larvae by Vignau et al. (1997). The average larvae/g for the three most heavily infected muscles was 4951.3 larvae/g (masseters), 5081.8 larvae/g (tongue), and 5642.2 larvae/g (diaphragm) compared to 1400 larvae/g in the lesser infected triceps, intercostals and quadriceps muscles. These results suggest that rats scavenging off a moderately infected carcass would have a high number of encysted larvae present in muscle groups used for testing.

It is likely that any larvae in our samples would be dead following storage at -18°C as *T. spiralis* have been found to no longer be viable after 2-10 days at temperatures below -16°C (Smith, 1975). There was a concern during testing that freezing the rat, cat and mustelid samples may adversely affect recovery of larvae. Freezing was necessary as collection took place over a wide area and time frame. Smith (1975) reported that as temperatures dropped to below -16°C, trichinae larvae were recovered in lower numbers, and this decline continued as the storage temperature decreased. Although the non-living outer cuticle of *T. spiralis* increases the likelihood of recovery from frozen carcasses compared to other parasites, there is evidence that fresh samples give more accurate recovery counts (Shoop et al., 1987). Our samples were stored at -18°C and it is possible that this biased our results. If larvae were present in the meat, but damaged by the freezing process, they may not have been recovered effectively by the pepsin digest method. Findings by Henriksen (1978) suggest a method by which larvae are retained and stained on disposable sieves giving a 100% recovery of larvae from samples stored at -20°C, although this method has not been mentioned in more recent articles.

Sieve size affects the type of larvae recovered from the digest. Recovery rates of larvae may be good from the finer 180 µm sieves when larvae are tightly coiled, and are poor when larvae are either motile or dead (c shaped) (Gamble, 1999). Gamble observed that dead larva were recoverable; however they did not pass through the sieve as readily as chilled or live worms, and smaller sieve sizes may increase this problem. In the present study, the initial 100 samples were processed with a 180 µm sieve and the subsequent samples were sampled with a 300 µm sieve. Hence the recovery from latter

samples should not have been adversely affected by sieve size. Also settling time was greater for non-motile worms; an important consideration given our testing was carried out on larvae that had been frozen. However, the verification test showed that non-motile larvae could be recovered from a digest mixture using our filtering process.

The completion of the digestion procedure was a concern during this study. We used 0.4% pepsin and 1.6% HCL, compared to the MAF directives that recommend 0.5% pepsin and 0.8% HCL. International recommendations are to use 1% pepsin and 1% HCL (Gamble, 1999; Nockler et al., 2000). A higher concentration of pepsin increases the likelihood of digesting the larvae, particularly if they are damaged (Gamble, 1999). From this respect, the lower percentage of pepsin used in our study would have been beneficial in the recovery of worms that had been frozen. As no positive samples were available for test validation, the digestion process in our study could only be monitored visually to ensure that meat samples were thoroughly broken down.

Review of current literature on the ecology of *Trichinella* and case reports of outbreaks worldwide suggest that rats may not be the most reliable indicator for the presence of *T. spiralis* in the environment (Pozio, 2000; Pozio, 2001). Mexico City and the State of Mexico are both provinces that have a high incidence of human and swine trichinellosis. Recent surveys carried out in Mexico have found prevalence results ranging from 15.0% in cats to 0.9% in rats from the same area (Ortga-Pierres et al., 2000). Similar accounts of a very low prevalence in rats compared to foxes, dogs or cats tested from the same area have been found in Italy, Thailand and New Zealand (Pozio et al., 1996; Takahashi et al., 2000; Thornton and King, 2004)

Adequate tissue sample sizes and numbers of rats may be the cause of sampling inconsistency when testing rats. A minimum of 1 g of muscle tissue is sufficient to detect *Trichinella* where the aim is to prevent clinical trichinellosis (Gamble et al., 2000). However, in animals with a low level of infection, larvae are not usually evenly distributed, and so larger samples are preferable (Nockler et al., 2000). Some studies have used the foreleg muscle instead of muscles from the head when testing rats, which suggests this study could have considered digesting the forearm muscles as well. This would have increased the muscle mass available for testing which improves the sensitivity of the test.

The number of samples collected affects the precision (how closely the sample statistic predicts the true prevalence) and accuracy (level of confidence) of the outcome value. Sample sizes are usually derived from a known population size; however, this study tested wildlife, which presents an unknown population size. For this reason cluster sampling analysis techniques were employed (Bennett et al., 1991). A drawback of cluster sampling is that it reduces precision. If the 95% confidence interval is greater than the estimated prevalence, then false negatives are likely to occur. To find a very low prevalence the testing needs to be very precise. For example, using an average cluster size of 11.5, 355 clusters are required to detect disease at 1%, with a 95% certainty of the result being within 0.5% of this estimate.

In order to attain a 95% confidence level, 240 rats were required if the true prevalence was 6% and the testing precision was +/-3%. The 1968 investigation at the Feilding landfill achieved a confidence level of over 90%, which suggests that the prevalence found then was a reasonable representation of the true prevalence at the landfill at that time (Liberona and MacDiarmid, 1988).

Rat samples were representative of the population, as the weight ranges for both species gave a normal distribution, with average weights that concur with those previously recorded in New Zealand (Innes, 1990; Moors, 1990). The mean weight for Norway rats found in this study was about 50 g heavier than that found by Moors (1990), however, he does acknowledge that commensal animals tend to be larger than the weights he quoted, and our samples include landfill rats, which were larger than those found on the piggeries and DoC land.

Enemark (2000) found that infection appeared to occur at high numbers in localised areas. This is likely the case in New Zealand, given the sporadic occurrences of trichinellosis over the last 70 years, so the number of rats tested in this survey may have been insufficient to give a realistic indication of prevalence. However, samples were collected from areas of concern (piggeries), or areas considered a risk (landfill and native bush), to improve the chance of detecting *T. spiralis* in the environment.

Our study strongly suggests that there is a difference in habitat preferences between rat species. As only Norway rats have been found to carry *T. spiralis*, it is likely that some areas pose a higher risk of infection than others from resident rat populations.

Norway rats were caught more frequently than ship rats in piggeries, while in rubbish dumps only Norway rats were recovered. A preponderance of Norway rats compared to ship rats in landfills concurred with findings by Wodzicki in 1950 (King, 1990), and trapping data from Brockie (1977). Therefore, landfills could pose a significant risk for *T. spiralis* transmission, especially as they provide access to meat scraps from a wide variety of sources. Prior to the New Zealand outbreak in Whangamata in 2001, the local landfill was closed, and a transfer station established. It has been suggested that rats from the closed dump then migrated down the valley. In contrast, mainly ship rats were found in DoC lands, which was consistent with other reports (Innes, 1990; Moors, 1990). Consequently the risk of *T. spiralis* being transmitted or maintained in conservation areas is small and the risk of a rat reservoir transferring *T. spiralis* to feral pigs is minimal.

The low number of rodents collected from landfills may be due to changes in landfill management. Old management methods saw landfills piling rubbish up, and when the pile became too large the tip face was moved along the valley or site. The current management system involves active management of rubbish within a confined area which limits secure nesting sites for rodents as the rubbish is being turned over, moved and compressed frequently. Rubbish may be moved daily to monthly, depending on the volume of rubbish delivered to the dump. The Feilding landfill where rats were seen during rubbish compaction was an older, smaller, site where compaction only occurred monthly. The national plan is to replace all landfills with engineered dumps by 2010 (Coralde, 2003). These engineered dumps are deep concreted-lined holes and designed to produce gas to be removed using a pump system and processed for further use. These plants will take 1-1.5 years and ~\$10 million to build. The closure scheme has begun at the Palmerston North landfill, and will conclude in 2007. If this decline in rodent numbers is real, then the further tightening of landfill management is likely to reduce rodent infestations further. Lower numbers of rodents in landfills lowers the potential risks that they may spread disease, including *T. spiralis*.

In conclusion, this study did not find any evidence of *T. spiralis* in New Zealand wildlife captured from commercial piggeries, conservation areas, and landfills. The low number of samples recovered from each environment adversely affected the accuracy of the testing method. This was particularly relevant to DoC lands, where only 10 Norway

rats were recovered. Despite the low sample numbers, it is believed that the pepsin digest testing method used should have been sufficient to detect infection had it been present in the samples. There were marked differences in the numbers of ship rats and Norway rats in different environments, suggesting there is a higher risk of rats transmitting *T. spiralis* around landfills than DoC areas, as only Norway rats have been known to carry the parasite, and these were more common on landfills than DoC land.

3 Survey of farm management practices on commercial piggeries in New Zealand

3.1 Introduction

Trichinella spiralis is a zoonotic parasite that has been successfully controlled by veterinary meat inspection and improved piggery management practices (Davies et al., 1998; van Knapen, 2000; Kociecka et al., 2003). However, in production settings without adequate control measures, such as veterinary inspection and effective on-farm management, the parasite still persists as a food safety problem (Pozio, 2001; Stojcevic et al., 2004). Practices that have been identified as key in the transmission of *T. spiralis* in piggeries include feeding raw food-waste to pigs, contact between wildlife or rodents and pigs or pig feed, and unsafe carcass disposal practices on farms (Leiby et al., 1990; Murrell and Pozio, 2000; van Knapen, 2000; Bessonv et al., 2003). In order to compare New Zealand farming practices to those known to minimise the risk of *T. spiralis* transmission, routine management practices on New Zealand commercial piggeries need to be determined.

Production methods for rearing pigs can vary greatly in New Zealand, but information about management practices in New Zealand commercial piggeries has been poorly documented and few surveys have been conducted. Surveys are a useful method for collecting information about a target population (Thrusfield, 1995). Survey information can be collected through various means, including mailed questionnaires. Benefits of mailed questionnaires include faster response rates, lower costs, and often more valid responses in comparison to telephone and personal interviews. However, low response rates are a problem with mailed questionnaires, which can reduce their effectiveness in accurately representing the target population (Christley et al., 2000).

The aim of this study was to gain information about common management practices on New Zealand commercial pig farms, particularly those that may effect the transmission of trichinellosis. A survey was conducted to better understand pig management practices in New Zealand. This survey included only farms having over

100 breeding sows or 640 grower pigs¹. This permitted an evaluation of production practices common to commercially viable pig farms. A particular focus of the survey was on management factors thought to relate to the control of rodents. Commercial piggeries were targeted because they were herds eligible for pork export.

3.2 Method

3.2.1 Study design

Piggeries for the survey were selected on herd size from the national Pork Industry Board database of New Zealand piggeries. Surveys were sent to all piggeries with over 100 sows or 640 grower pigs. The questionnaire was designed to establish basic piggery characteristics such as: herd structure and size, the age of piggery buildings, feed types used, what animal species (other than pigs) are in close proximity to the piggery, types of land use surrounding the piggery, levels of rodent activity on the piggery, rodent control methods used and the level of awareness of the parasite *Trichinella*. The survey form was trialled with three commercial piggery owners and a Pork Industry member prior to being sent. The survey form and cover letter are presented in Appendix 3.1. The survey was made confidential through the use of unique identification numbers, so that the forms themselves had no personal details on them. The investigator could still match data with location etcetera through matching the identification numbers with personal details in a separate database.

Piggeries were made aware of the study before the survey was sent out through an announcement published in “Pork Outlook”, the New Zealand Pork Industry Board monthly newsletter; a publication received by all known piggeries in the country. Through this publication, piggeries were informed of the date when the survey would be sent out and encouraged to complete it and return it. To facilitate the return of the survey, the survey form was sent out with a reply-paid, pre-addressed envelope. Respondents were thanked by letter (see Appendix 3.2) and non-respondents were contacted by up to two phone calls to further solicit the completion and return of the survey.

¹ The number of grower pigs was estimated on 16 weeks of production from weaning to slaughter; given that on average 100 sow herds would produce 40 pigs a week.

Completed surveys were entered into a Microsoft Access (Microsoft Corporation, 2003) data base. Tables from the access database were exported to Microsoft Excel 2003 (Microsoft Corporation, 2003) for data analysis.

3.2.2 Descriptive analysis

General

The results of the survey data were summarised by question. Some of the results could be interpreted directly, for example, whether or not the rats were widespread or localised. However, some questions required further manipulation, or recoding of the data.

Survey performance

The term ‘Non-respondent’ was used for two different instances; either for someone who did not return the survey, or for someone who returned the survey, but did not answer a particular question. If any particular question was missed in a returned survey, that piggery was recorded as a ‘Non-respondent’ for that question only, and this piggery was not included when assessing the results for that question. As a consequence, the total number of piggeries represented for each question may vary slightly. Respondents were used to assess the return rate of the survey. Non-respondents for each question were assessed to see how well the survey was answered by farmers.

Herd characteristics

The number of pigs on the farm was asked for, followed by a brief assessment of the housing types used for each production category. The term “conventional sheds” was used to refer to traditional housing, which typically involves keeping pigs inside buildings in pens, either singularly or in small groups. A different, more recent trend in pork production has been to raise pigs in “eco-barns”. Eco-barns are low-cost shelters in which the pigs can wander freely within the confines of the shed. Lastly, this section included a question on the approximate age of piggery buildings.

Feedstuffs and sources

This section asked general questions on what types and sources of feed were used on the piggery and how they were stored. The use of the term “compound feed” was used in reference to a commercially prepared, pre-mixed feed. This type of feed may, or may not have been heat treated or pelleted and was designed as the complete diet for a

specific production group. The survey enquired about the feeding of by-products, and if so, what type was fed. The term “by-product” included any food that was produced as a consequence of food or other production, where the main product being produced by the process was not pig feed.

Farm environment

Numbers of staff were assessed in relation to total pig numbers on the farm. The average value of pigs/staff ratio was calculated once extreme outliers were removed. When assessing the time until disposal for dead pigs, piglets, and afterbirth, some respondents replied “same day”. This response was recorded as eight hours, as time until disposal was assessed as the maximum time that dead porcine tissue was left in the vicinity of the piggery. This section also questioned what animal species other than pigs were found on or within close proximity of the piggery, and what types of land-use may be found around the piggery.

Rodent activity

Rodents are considered to be directly involved in the transmission of *T. spiralis* on piggeries. Questions in this section of the survey were designed to assess the levels of rodent activity on piggeries. Rodent activity on the piggery was assessed using three questions each for rats and mice. The six questions regarded how often evidence of live rodents, dead rodents or rodent droppings were seen in the piggery. Farmer responses per question had to be aggregated in order to summarise the outputs from the questions into a single rating, one for rats and one for mice, for each piggery. Evidence of rodents was given a grade by respondents out of three possible options, either ‘Regularly’, ‘Occasionally’ or ‘Never’ seen on the piggery. These grades were allocated a 2, 1, or 0, respectively, by the investigator.

The activity rating from each question was calculated to give an overall outcome value of high, medium, or low activity. Activity was calculated by weighting each grade by question. The response value for live rodents was multiplied by six, dead rats by three, and droppings by one (see Table 3.1). An overall value of less than six was considered to be *low* activity. Values recorded from six to 11 were considered to indicate *medium* activity. Values greater than 11 represented *high* rodent activity. Activity level was scored separately for rats and mice.

Table 3.1 The system used to uniquely identify high, medium, or low activity.

Question : How often do you see... ^b	Farmer response ^a		
	Regularly (2)	Occasionally (1)	Never (0)
Live rats on your farm? (6)	12	6	0
Dead rats on your farm? (3)	6	3	0
Rat droppings and holes? (1)	2	1	0

^a Value given to each observation level is in brackets.

^b The value that each reply is weighted by to demonstrate the relative importance of that observation to rodent activity is in brackets.

Rodent control

Piggeries were asked what type and form of rodent control was used on their piggery, such as trapping, baiting, other animals, or contracting a professional pest controller. The questionnaire presented a selection of eight brands of commercial rodent bait for assessing which baits were most commonly used in piggeries. Characteristics of these eight baits are outlined in Table 3.2. Lastly, farmers were questioned on disposal methods of dead rodents found on the farm.

Table 3.2 Brand name, toxicant and distributor for eight rodenticide baits available in New Zealand.

Product Name	Toxicant	Distributor
Pestoff	Brodiacoum ^b	Animal Control Products
Contrac	Bromodiolone ^b	Pest Management Services
Ditrac	Diphacinone ^a	Pest Management Services
Racumin	Coumatetralyl ^a	Bayer-AG
Talon	Brodiacoum ^b	Crop Care Holdings Ltd.
Storm	Flocoumaten ^b	Cyanamid NZ Ltd.
Kiwicare	Coumatetralyl ^a	Kiwicare Corporation
Baraki	Difethalone ^b	Agrevo

^a First generation anticoagulant

^b Second generation anticoagulant

Trichinella

In order to ascertain the general knowledge of piggery staff on *Trichinella*, three questions were asked on whether they were aware of the parasite and how pigs or humans may become infected.

Comments

A comments section was given at the end of the questionnaire for farmers to add any further opinions or ideas on the subjects raised in the survey form.

3.2.3 Univariate analysis of rat activity

All survey questions with a binary out-put were analysed against high or low rat activity to assess whether relationships existed between rat activity and on-farm factors. The small survey size did not allow for running the univariate analysis with the three rat activity categories used in the questionnaire of “Regularly”, “Occasionally” and “Never” (see section 3.2.2 Rodent activity), and so rat activity was re-categorised into high and low to create a binary variable for the univariate analysis. The only way of a farm having a score of 10, was to check the category “occasionally” for all three rat activity questions (Table 3.1). Activity was not considered “high” if all sightings were only occasional, particularly as the category “occasionally”, could be broadly interpreted by people answering the questionnaire. As there is a wide variation on the estimates of actual rat numbers when only one or two live rats are sighted, it must be assumed that regular sightings indicate a high rat population in the area. For these reasons it was decided that activity scores 10 and under were labelled as “low” for the binary outcome (binary value = 0), and activity scores over 10 were labelled as high (binary value = 1).

Rodent activity scores were used from the descriptive analysis of rat activity as outcome variables in a univariate analysis in SAS version 8.2 (1999-2001 by SAS Institute Inc.). Each on-farm factor (as displayed in Appendix 3.4) was used as an explanatory variable and compared using a 2x2 table. The Mantel-haenszel test was used to assess whether or not the on-farm factor had an affect on rat activity. Where cells had an expected count of less than 5, the Fisher’s exact test was used in place of the Mantel-haenszel test. Four piggeries were removed from the analysis as they had missing values for the outcome category.

3.3 Results

3.3.1 Survey performance

The survey was sent to 123 piggeries, of which 85 herds responded (69% response rate). Raw data is presented in Appendix 3.3. Thirty-eight percent of the 85

respondents filled in every question in the questionnaire; 40% neglected to answer either one or two questions. Overall, 78% of the returned questionnaires had at least 95% of questions answered. Non-respondents were contacted by telephone but this only resulted in five additional surveys. Reasons for non-response included the farmer being unwilling to participate, unable to be reached with two phone calls, or the piggery operation was no longer in business.

Out of the 37 survey questions, 41% were completed by all respondents. Of the remaining 22 questions, only four were not answered by 10 or more respondents (see Table 3.3). The other 18 questions were each, on average, not completed by four respondents, but this number ranged from 1 to 8.

Table 3.3 Survey questions that had high non-response rates.

Question number	Question asked	Number of farmers that did not respond
2a	How were your dry sows housed?	14
2b	How were your lactating sows housed?	12
26	Roughly, how many bait stations are on your farm?	10
28	Approximately how many rats per month do you catch in traps?	18

3.3.2 Herd characteristics

On average, piggeries responding to the survey had 314 sows (see Table 3.4). Some farmers did not respond to this question, or indicated that they did not keep pigs of that particular class. The average total number of pigs including sows kept on a surveyed piggery was 1,795. Conventional sheds were used to house 82% of grower and finisher pigs. The other 18% of grower and finisher pigs were housed in low cost shelters such as eco-barns. The average minimum age of buildings on farms was 8 years (range 1 - 30 years), and the average maximum age for a building on the piggery was 31 years (range 9 - 105 years).

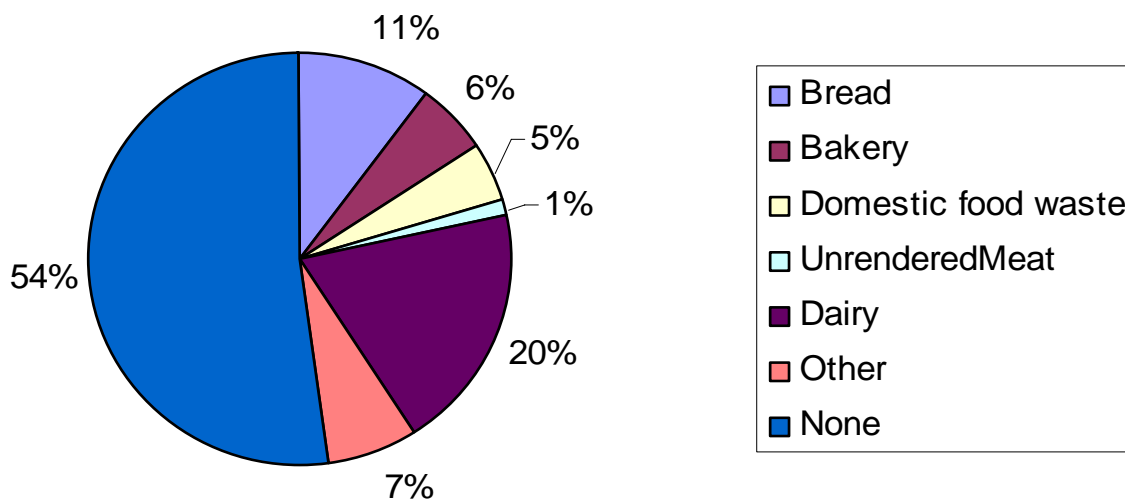
Table 3.4 Number of pigs in surveyed piggeries.

Class	Number of piggeries	Median	Minimum	Maximum	Did not respond or zero
Sows + Mated Gilts	73	220	30	2800	12
Unmated Gilts	72	20	6	212	13
Weaners	82	510	100	4500	3
Growers	79	440	24	6000	6
Finishers	67	482	60	5000	18

3.3.3 Feedstuffs and sources

Out of the 31 farms that fed compound feed, 55% fed compound feed exclusively. The other 68 piggeries fed a mix of feeds. Of the piggeries that fed mixed diets, 92% fed grain, 94% fed meat and bone meal, 79% fed blood meal, 87% of piggeries fed soy, 75% fed fish meal and 20% fed compound feed along with the other feeds. Of the 34% of piggeries that fed ‘other’ types of feed (that were not by-products) most were referring to the use of milk powder.

The majority of surveyed farms did not feed by-products (see Figure 3.1). For those that did, most fed dairy by-products. Only one farm recorded feeding un-rendered meat as part of food waste that included garbage, bread, calves and chooks. However, this farm thoroughly processed all meat products using heat treatment before being fed to pigs. Four piggeries were found to feed domestic food waste to their pigs.

**Figure 3.1** Types of by-products fed by commercial piggeries.

3.3.4 Farm environment

The average ratio of pigs per farm staff member was 580 (standard deviation = 180). The highest ratio of pigs to staff was 1700 pigs/staff. There was a positive correlation between pig numbers, and staff numbers ($R^2 = 0.478$).

Only 48% of respondents recorded the presence of wild birds on the piggery. As it is unlikely that wild birds could be excluded from most piggeries, it is likely that this question was misinterpreted by some farmers. However, it is possible that wild birds can be excluded from confinement pig sheds if the sheds are bird proofed with mesh or wire.

Over 90% of respondents had animals other than pigs on their farm (see Figure 3.2). Most farms had three to four other species of animals on the farm.

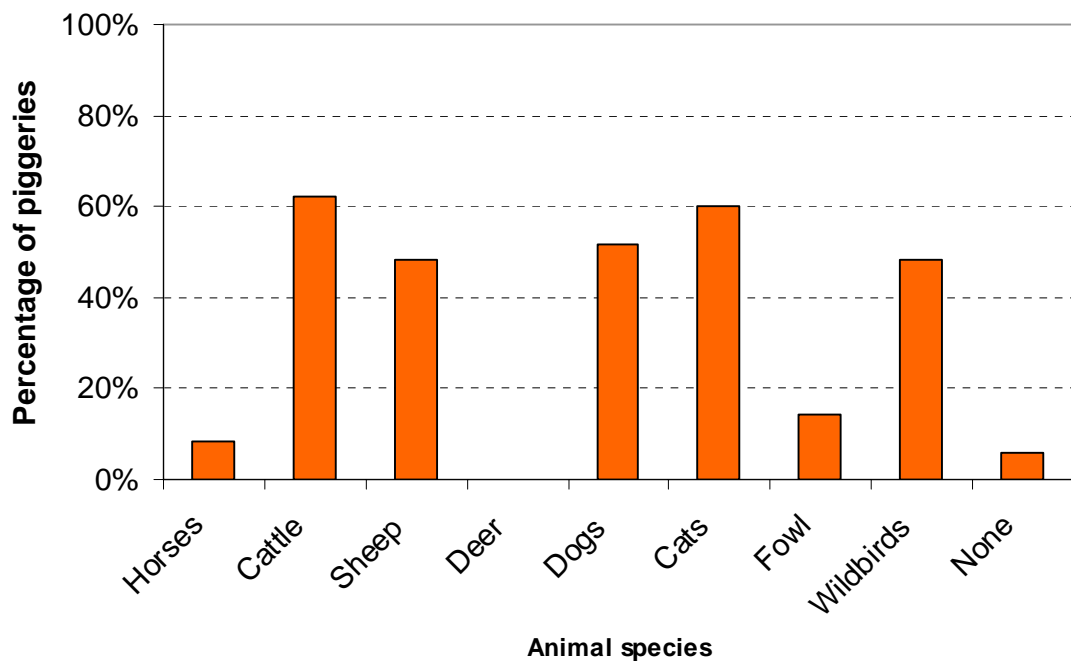


Figure 3.2 Animal species, other than pigs, present on the piggery and in close proximity to buildings containing pigs.

Dead pigs, piglets and afterbirth were mainly disposed of on-farm, by either composting, or through use of an offal hole (see Figure 3.3). It was rare that piggeries disposed of pigs into general rubbish pits, and no piggeries disposed of pigs by feeding them to other animals. The maximum length of time until disposal for 78% of piggeries was 24 hours. A further 16% of piggeries took up to 48 hours to dispose of pigs and the remaining 6% of piggeries took anywhere up to seven days. The question asking for time until disposal had seven non-respondents.

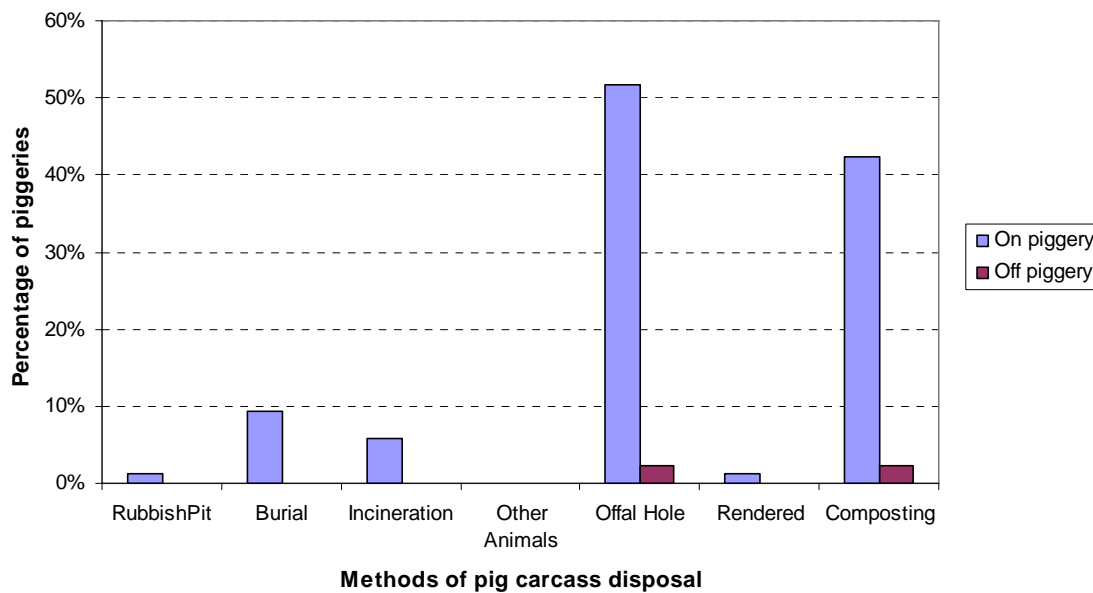


Figure 3.3 Methods used by piggeries to dispose of dead pigs, piglets and afterbirth.

The two most common types of land use found within a 500 m radius of surveyed piggeries were livestock (89%) and private housing (51%). The least common use of land around piggeries was native bush (11%), and miscellaneous categories (11%), such as a golf course, streams and lifestyle blocks. Forestry and grain crops were found around 24% and 28% of piggeries, respectively.

3.3.5 Rodent activity

Surveys from four piggeries could not be included for analysis of rat activity as they were missing replies to one or more questions. Parameters for the uncategorised data is given in Table 3.5. From 81 responses for rat activity, 63% of farms responded with a score of ten. A score of ten meant that live rats, dead rats, and rat droppings were all seen occasionally.

Table 3.5 Summary of uncategorised ratings of rodent activity on farms.

	Range (minimum,Maximum)	Quartile values		
		Median	25 th percentile	75 th percentile
Rat	11 (0,11)	6	6	6
Mouse	20 (0,20)	10	10	13

Categorised activity data

The majority of farms had medium levels of rat activity as shown in Figure 3.4.

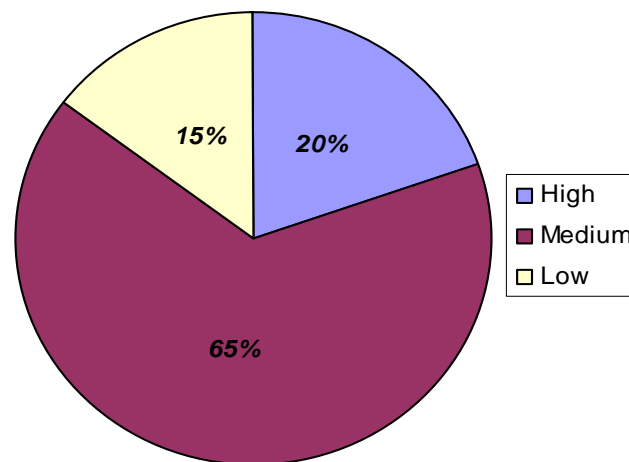


Figure 3.4 Percentages of high, medium and low rat activity identified on surveyed piggeries.

Surveys from six piggeries could not be included for analysis of mouse activity as they were missing replies to one or more questions. Figure 3.5 demonstrates that similar numbers of farms exhibited either medium or high mouse activity.

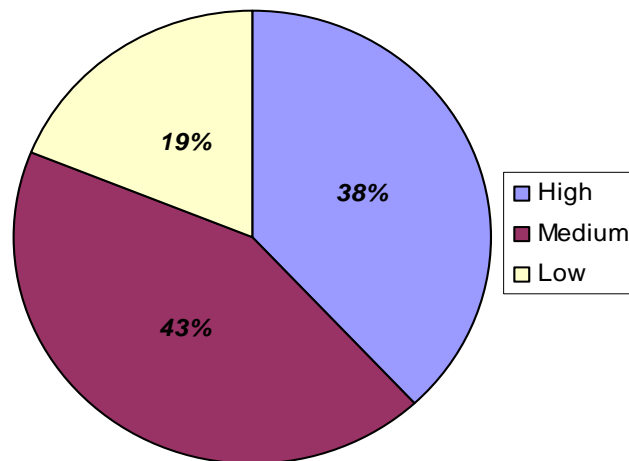


Figure 3.5 Percentages of high, medium and low mouse activity identified on surveyed piggeries.

Location and seasonality of rodent numbers

The percentage of piggeries that reported seeing rats widely distributed throughout the piggery (42%) was similar to those that reported seeing rats in one localised area (58%). The majority of farms (77%) did note that rodent numbers fluctuated with season.

Cats in piggeries

Thirty-three piggeries of the 85 surveyed (39%) did not have cats living on the piggery. Of the 61% of piggeries that did have cats, the mode was three cats, with a range from 1 to 20.

3.3.6 Rodent control

Over 90% of piggeries used poison baits to control rodents on the premises (see Figure 3.6). Most piggeries (72%) laid out poison baits to target rats and mice at least once a month. The second most common method of rodent control was through the use of dogs and cats. Few piggeries used professional pest control companies. Only one piggery did not have a form of rodent control on their piggery, although this farm did report seeing rats on the piggery.

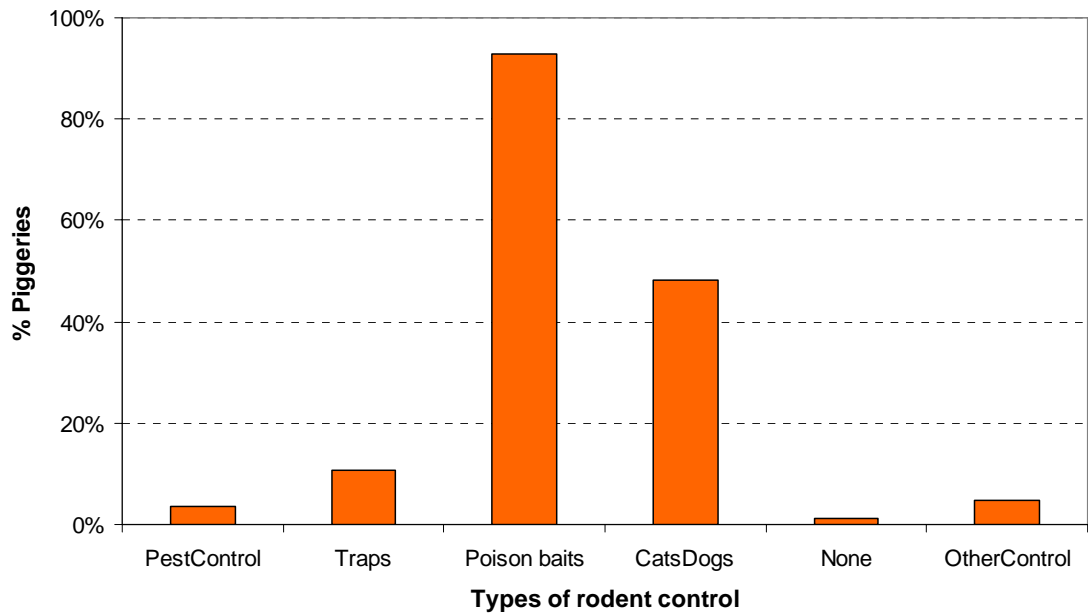


Figure 3.6 Types of rodent control used on commercial piggeries.

The most common brands of bait used on the piggeries was ‘Talon’ (62%), ‘Storm’ (49%) and ‘Racumin’ (34%) (see Figure 3.7). ‘Ditrac’, ‘Kiwicare’ and ‘Baraki’ were only infrequently used.

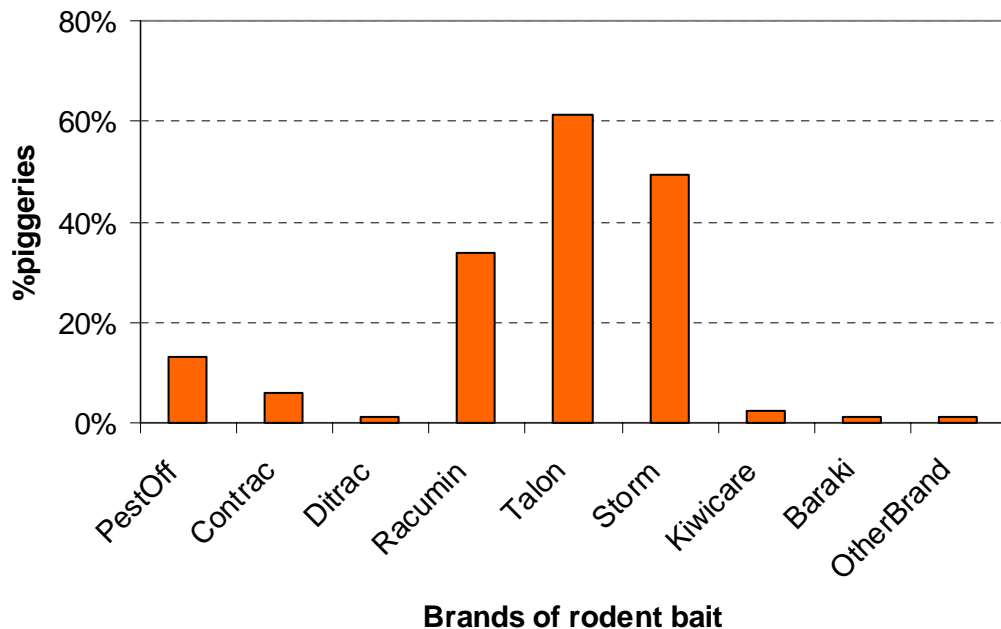


Figure 3.7 Brands of bait used by commercial piggeries.

3.3.7 *Trichinella*

The survey found that 82% of respondents had heard of *Trichinella*. Fifty-eight percent of respondents correctly answered that the parasite was transmitted through under-cooked pork products.

3.3.8 Univariate analysis of rat activity

The full results of the univariate analysis are presented in Appendix 3.4. Only one variable showed a significant relationship with high rat activity, this was having private houses on surrounding land within 500m of the piggery ($P= 0.04$). The percentage of respondents answering yes to private land use around their piggery was 51.8%. Two other variables were just higher than the 0.05 P -value cut-off. These two values were using ‘other’ types of housing for lactating sows (P -value =0.06), and having dogs around the piggery (P -value =0.08). The first of these only had a 5.9% of respondents, and the later had a 51.8% response to it. A further 12 variables had a P -value of less than 0.2. This would suggest that they may be suitable for further analysis using a multivariate model. However, time constraints on the project did not permit further data analysis.

3.4 Discussion

The high survey response of 69% achieved in this investigation enabled a thorough study of the management practises occurring on commercial pig farms in New Zealand. Two additional pig-related studies used surveys to collect data in New Zealand in 1998 and 1999. One focused on pig respiratory diseases (Gregory, 1999) and the other on sow housing (Stark et al., 1998). The study by Stark et al. (1998) had a response rate of 37.2% with a total of 116 sampled piggeries, the survey by Gregory (1999) used 76 herds to assess the accommodation situation for New Zealand sows. Our results based on 85 herds (69% response rate), compare favourably with the coverage achieved from the two previous studies, both of which were nationwide surveys.

The survey identified management practices believed to either increase or decrease the risk of *Trichinella* transmission on piggeries. Some practices thought to increase the risk were only noted on a small number of piggeries and were not representative of the wider group, but nonetheless these practices should be noted. The most concerning finding was that 6% of piggeries fed domestic food waste. Feed of this type raises

biosecurity issues for a range of diseases (Lawson and Zhou, 2005). “Domestic food waste” was a broad category, and the exact food types in this waste were not defined in the survey question. Uncooked waste food is also a risk factor for the transmission of *T. spiralis* (Pozio, 2001; Bessonv et al., 2003; Joshi et al., 2005). Contrary to this, an American study did not find a significant association between feeding waste and trichinellosis in pigs (Gamble et al., 1999). Further, 6% of farms fed bakery by-products; again these products are a risk factor for introducing disease.

Forty-seven percent of piggeries reported feeding any by-products. The major class of by-products fed were of dairy origin, which is not thought to pose an increased risk for introducing *T. spiralis* into the piggery. Similarly, bread-only was fed on 11% of piggeries, but again this is not a high risk by-product feed. By-products reported under the “Other” category, were all non-meat items, and most were recorded as milk powder or dietary additives such as copra, whey and amino acids. The only exception to the latter was kiwifruit and potato chips fed on two separate piggeries.

Two additional concerns identified in the survey were the presence of cats on 60% of piggeries and the use of composting and offal pits for pig disposal. If not well managed, these practices can create the opportunity for rats or cats to scavenge pig carcasses. However, as only 6% of piggeries took more than 48 hours to properly dispose of carcasses; this does not appear to be a widespread problem. Few piggeries disposed of pigs off-farm. In the current New Zealand pig industry, disposing of pig carcasses off-farm would be particularly difficult for piggeries situated in areas that are becoming more urbanised. New Zealand piggeries are, in many cases, part of a larger farm, so ‘on-farm’ may be some distance from the piggery. Recommended practice by the 2001 United States Department of Agriculture (USDA) Trichina-free certification program is that carcasses be disposed of at least 100 feet (30.5 m) away from swine housing; this should be readily achievable on most New Zealand piggeries (Anon., 2001). The disposal of dead pigs, piglets and fetal membranes within 24 hours was commonly practised on surveyed piggeries, as 78% of piggeries disposed of them within this time frame. Both the International Commission on Trichinellosis and the USDA recommend that the materials be properly disposed of with 48 hours (Anon., 2001; Bessonv et al., 2003).

Rats and mice can introduce disease onto farms, as well as spreading diseases between sheds on a farm (Le Moine et al., 1987; Corrigan, 2001). Rodents and wildlife present on farms are considered principle risk factors for the transmission of *Trichinella* in farmed pigs (Leiby et al., 1990; Gamble et al., 1999). Eighty-five percent of piggeries (85%) in this survey reported medium or high rodent activity. High standards of biosecurity cannot be assured on a piggery that harbors rodents.

Four different rodent baits containing 2nd generation anticoagulants were reported as being used on surveyed piggeries. Two of these baits, ‘Talon’ and ‘Storm’ were the most commonly used baits on piggeries; the other two baits, ‘Pestoff’ and ‘Contract’ were 4th and 5th most commonly used. As second generation anticoagulants are more toxic than first generation anticoagulants, they require a lower intake (single-feed bait) to cause death. However, they are also at higher risk for causing secondary poisoning in non-target species (Cairns, 1966). The third most commonly used bait by piggeries was the first generation bait ‘Racumin’. First generation anticoagulants are more rapidly metabolised by animals so a higher intake (multi-feed bait) is required to cause death. Consequently, they are at lower risk for causing secondary poisoning (O'Connor and Eason, 2000). The potential for swine to consume second generation baits and the resulting potential for them to enter the human food chain has become a concern to some regulatory officials. In response to this concern, the Ministry of Agriculture and Forestry have started testing pork for residues of second generation anticoagulants. For these reasons, farmers may want to consider using a combination of improved farm sanitation measures and first-generation anticoagulant baits as a means of helping to ensure the production of residue-free pork. In wildlife conservation areas of New Zealand, one such bait ‘Ditrac’ is widely used, and is the preferred bait for targeting rat populations.

Questions related to sow housing and rodent control were not well answered, confounding interpretation of the results. All non-respondents for lactating sows housing had also entered either zero, or did not respond to the question regarding the number of sows on the piggery. Similarly, non-respondents to the question regarding dry sow housing, also did not enter sow numbers, with the exception of two piggeries. This may have represented different on-farm situations. The piggeries may only produce grower pigs, and not have sows on the property, or may have chosen not to

answer the question because sow numbers and housing are sensitive issues currently in the pork industry as they are related to welfare and the number of Pork Industry Board votes that the farmer is allocated. The survey could have been improved by having a “Do not wish to answer” or “Grower herd only” box, which is similar to the “None” option used in later questions. Similarly the questions asking for numbers of baits stations and numbers of rats caught in traps, would not have been applicable to some farmers, and these questions would have benefited from a further option box. Hence the poor response to some questions could have been avoided by survey design. Similarly, a mail out questionnaire to veterinarians attributed poor responses to particular questions to the absence of an ‘unsure’ category (Christley et al., 2000).

Questions generally appeared well answered. However, some wording problems became apparent once data analysis started. Time to disposal was not well worded as it asked how long dead pigs were left before disposal, but did not state the unit of time that the answer was to be answered in. As a result, some answers were in days and some in hours. Difficulties in interpretation came about when the recorded response was ‘daily’, or ‘same day’ or ‘0.5 day’, as these could be referring to either the 24 hour day, or the 8 hour work day. Due to this the outcome of the time for disposal may vary from that found from the survey results. Also when asking about forms of rodent control, cats and dogs were grouped together, this is likely to have created a biased result if only one of the two were in fact usually used for rodent control.

Although a significant result was found between higher rat activity and private houses in the nearby vicinity, this outcome may have been confounded by other factors. For example, piggeries with a lot of housing around them are often older piggeries where housing developments have slowly been built closer and closer to the already established piggery, and newer piggeries are likely to be built well away from urban development. If this is true, it may be the age of the piggery is affecting rat numbers, and not the proximity of private dwellings.

The results of this survey suggest that those management practises known to increase the risk of transmitting *Trichinella* to commercially reared swine occur only infrequently on New Zealand farms supports the very low incidence of trichinellosis in domestic pigs recorded in the country. The main area that needed improvement in piggeries was rodent control. Overall most piggeries safely disposed of carcasses, and

fed non-meat containing by-products. Government legislation does not allow the feeding of raw garbage to pigs, which reduces the chance of infection from this source. The survey found a high general awareness of *Trichinella* by piggeries; however, there was some uncertainty of the transmission pathway of the diseases between pigs and humans.

4 Factors affecting rodent activity during intensive poison baiting on New Zealand commercial piggeries

4.1 Introduction to Rodent pests

Commensal rodents such as rats and mice are pests that cause economic loss worldwide (Le Moine, Vannier et al. 1987; Corrigan 2001; Endepols, Klemann et al. 2003). On an annual basis one-fifth of the world's foodstuffs planted each year are damaged or eaten by rodents (Long 2003). Both rats and mice have been implicated in spreading diseases to and between both human and animal populations (Corrigan 2001). These diseases are a potential risk for animal health and human food safety (Carter and Cordes 1980; Bolt and Marshall 1995; Lo Fo Wong, Dahl et al. 2004).

There are three rodent species present on mainland New Zealand, the ship rat (*Rattus rattus*), the Norway rat (*Rattus norvegicus*) and the house mouse (*Mus musculus*) (King 1990). Rodents are now well established in New Zealand as they are opportunistic feeders and prolific breeders that adapt well to living in close proximity to humans and cause widespread damage to native birds (James and Clout 1996; Thorsen, Shorten et al. 2000). The majority of studies on the monitoring and baiting of rodent populations in New Zealand have been carried out for conservation purposes (Innes, Warburton et al. 1995; Thomas and Taylor 2001).

Rodent populations are a concern in livestock production facilities, especially intensive sites such as piggeries as rodents spread diseases to pigs, damage feed and cause structural damage to buildings (Corrigan 2001; Leung and Clark 2005). Diseases identified in rats that cause health and production concerns in New Zealand piggeries are leptospirosis, salmonellosis, toxoplasmosis, erysipelasosis, human cysticercosis, *Giardia intestinalis* and trichinellosis (King 1990; Marino, Brown et al. 1992). Despite problems related to rats and intensive farming, few New Zealand studies have looked at effective rodent control in piggeries.

The role of mice in spreading zoonoses is unclear and appears to be very minor in New Zealand (Tannock, McInnes et al. 1971; Blackwell 1979; Bolt and Marshall 1995;

Cork, Marshall et al. 1995). Mice can spread disease to swine through mechanical transmission. In addition to disease spread, mice damage about 10 times more food than they eat through contamination by urine and faeces (Long 2003). The risk of feed damage and disease spread from mice make their eradication important in piggeries.

Transmission in a swine herd of diseases such as trichinellosis has been prevented by removing rats from the piggery (Leiby, Duffy et al. 1990; Pozio 2001; Endepols, Klemann et al. 2003). This provides a high incentive for rodent control to be effective in piggeries. Rodent control in intensive, high activity livestock production facilities is a problem due to limited space, high food availability and the close proximity of livestock. Typical rodent control strategies used in America recommend an approach that includes sanitation of buildings, rodent proof building construction, reducing existing rodent populations and, lastly, an evaluation of the effectiveness of the programme (Corrigan 2001).

Studies by New Zealand's Department of Conservation (DoC) have used generalised regression analysis and spatial prediction models to analyse possum abundance and movements (Fraser, Overton et al. 2003). In 1996, Langton and others used logistic regression to investigate the key factors that affected the presence of rodents in a survey of urban houses (Langton, Cowan et al. 2001). Factors affecting rodent distributions can also be explored using Geographic Information Systems (GIS) to create maps depicting areas of rodent activity over time (Fotheringham and Rogerson 1994; Traweger and Slota-Bachmayr 2005).

The aim of the study was to assess the effect of an intensive baiting programme on rat and mouse activity on three commercial piggeries in the Manawatu using spatial and logistic analysis. Secondary to this, the study investigated rodent distributions on piggeries and the population dynamics within a rodent species and between rodent species.

4.2 Methods

4.2.1 Experimental Design

Data on rodent tracking activity was collected over 74 weeks between November 2002 and April 2004, from three commercial piggeries in the Manawatu, New Zealand

(-40.3° north, 175.6° east). Table 4.1 outlines the characteristics of each piggery in the trial. Piggeries 1 and 2 were sampled for rat activity 18 times and Piggery 3 was sampled 17 times during this 74 week period. One ‘sample’ was the collection of data from all tunnels on a farm. A total of 229 monitoring tunnels were used to monitor rodent activity in and around 24 sheds of varying types.

Table 4.1 Piggery and building area, number of baiting tunnels and pigs from three Manawatu piggeries.

	Piggery area (m²)	Building area (m²)	Number Tunnels	Sow numbers	Number of Grower pigs
Piggery 1	13,300	1,860	68	227	2,045
Piggery 2	14,000	1,330	70	156	1,408
Piggery 3	14,500	3,220	91	298	2,878
Total	41,800	6,410	229	681	6,331

Baiting activities ceased on the piggeries two months prior to the beginning of the study. The study period had four stages - (1) pre-baiting, (2) intensive baiting, (3) maintenance baiting, (4) follow-up baiting.; pre-baiting was from Week 1 to Week 4 (4 weeks), intensive baiting was from Week 5 to Week 6 (2 weeks), maintenance baiting was from Week 7 to Week 14 (7 weeks) and follow-up baiting was carried out by farm personal from Week 15 to Week 74 (59 weeks). Farm staff monitored bait stations and replaced bait where needed during the follow-up baiting periods. During the other three study periods, baiting was carried out by the investigator. The investigator visited the piggeries in all sample weeks and collected information on rodent activity. The experimental design is summarised in Table 4.2.

Table 4.2 The study design describes the date, week and study period of each sample collected from November 2002 to April 2004 (74 weeks). **The change in baiting practise between study periods by is highlighted through using different colours for each study period.**

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Date	Nov-02	Nov-02	Nov-02	Dec-02	Dec-02	Dec-02	Dec-02	Jan-03	Jan-03	Feb-03	Mar-03	May-03	Jul-03	Sep-03	Oct-03	Dec-03	Feb-04	Apr-04
Week	1	2	3	4	5	6	8	10	12	14	18	26	34	43	51	58	66	74
Study period	1	1	1	1	2	2	3	3	3	3	4	4	4	4	4	4	4	4

Stage	Baiting	Duration (Weeks)	Monitoring frequency	Dates
1	Pre-baiting	4	Weekly	Nov'02-Dec'02
2	Intensive baiting	2	Weekly	Dec'02-Dec'02
3	Maintenance baiting	6	Every 2 weeks	Dec'02-Feb'03
4	Follow-up baiting	56	Every 8 weeks	March'03-Apr'04

4.2.2 Monitoring Tunnels

Monitoring stations consisted of a 60 x 30 cm sheet of plastic core flute (Mico Plumbing Supplies, New Zealand) folded over a solid wooden base (Figure 4.1). Peanut butter was placed centrally inside the tunnel to act as a lure (Figure 4.1). The lure was replaced for each sampling session once a week. A tray holding an ink pad with tracking paper on either side was placed inside each tunnel, so that rodents would leave foot prints on the paper as they left the tunnel, after walking over the wet ink. Ink pads were approximately 7 cm x 17 cm and made from foam soaked in a dye consisting of 1:5 parts red food colouring to water, mixed together with 1 drop of non-fragranced shampoo. The shampoo was added to break the surface tension of the water, which increased the longevity and effectiveness of the dye.

The piggeries were sampled once a week and on the same night each week; Piggery 1 was sampled on Monday, Piggery 2 was sampled on Tuesday, and Piggery 3 was sampled on Wednesday. The tunnels were left overnight and the tracking paper and ink trays were collected the following morning. Tunnels were positioned late in the afternoon when general piggery duties had finished. Tracking papers were labeled with the tunnel location and collection date.

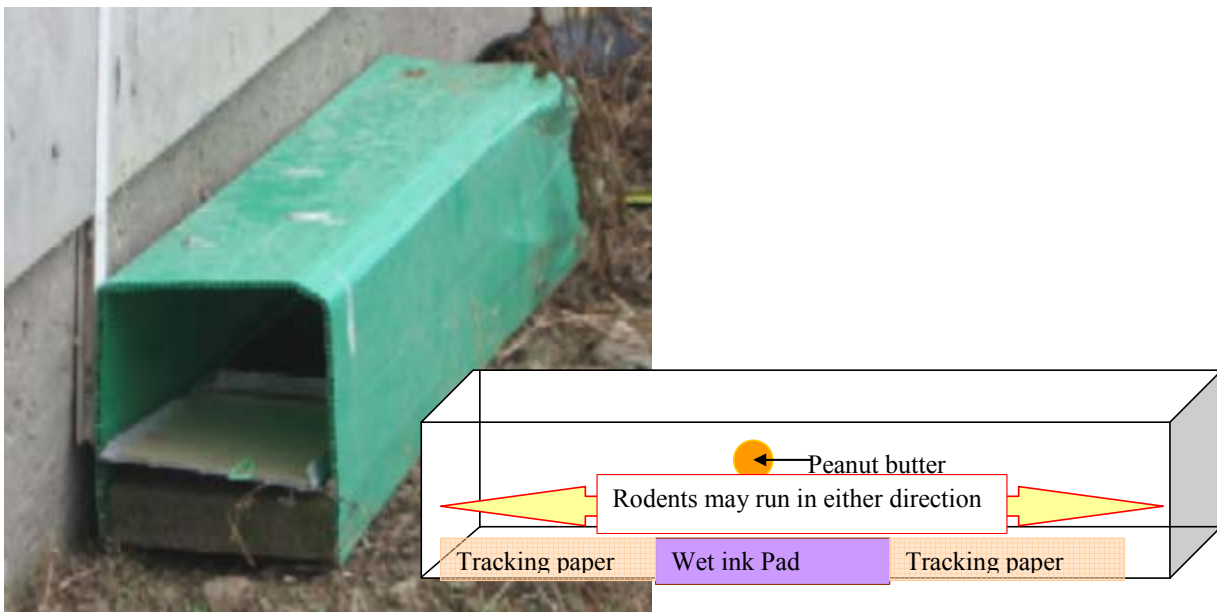


Figure 4.1. Photograph and diagram of a monitoring tunnel.

4.2.3 Tunnel location

A regular distribution of tunnels was used on each piggery. Buildings containing pigs had six tunnels evenly distributed inside, and four tunnels placed evenly around the

outside of the building. Inside tunnels were placed in each corner of the building and the remaining two were placed off the ground, or in aisles. Buildings not containing pigs (e.g. storage sheds), had up to four tunnels each placed throughout the building.

As building type varied widely within and between piggeries, tunnels sometimes could not be placed in the corners. In this case, tunnels were positioned to cover the area as evenly as possible. All tunnels, both inside and outside, were positioned with their long side flush to a wall. Individual piggery maps that show the positions of each monitoring station are presented in Figure 4.6 – Figure 4.8 and also in Appendix 4.1. These maps differentiate between tunnels placed inside and tunnels placed outside of buildings.

Pig movements and general piggery activities made it impractical to leave inside tunnels in place so they were stored elsewhere, undercover between study weeks. Outside tunnels stayed in position throughout the study period.

4.2.4 Poison baiting programme

Poisonous baits were laid out from the end of the 4th week of the study on each piggery. This study used the active ingredient bromadiolone (0.005%) in 28.35g (1 oz) blocks of commercial Contrac® rodenticide (Bell Laboratories Inc., Wisconsin, USA). Contrac® is a 'second generation' single feed bait designed for both rats and mice. Contrac® 1 ounce blocks had multiple edges to encourage gnawing by rodents and were easy to secure in bait stations as they are moulded with a hole through the middle. Pestoff® was compared for use in this trial because of its shape, but brief tests on the piggeries suggested it was not as readily eaten as Contrac®. Pestoff® appeared softer and less weather resistant than Contrac®, as was noted by O'Connor (2000).

The same baiting programme was followed on all three piggeries where bait was laid in bait stations throughout the piggeries in relation to the degree of rodent activity. Bait stations were laid out separately from monitoring stations. Bait stations consisted of an enclosed site where bait was secured to inhibit removal and exposure to non-target animals. Types of bait stations ranged from a jolt head nail inside a wall or vent to a commercial station (Figure 4.2). Most stations consisted 0.3 m sections of plastic down pipe or nova coil core flute (Mico Plumbing Supplies, New Zealand). Each station was supplied with between 1 to 8 individual blocks of bait depending on the level of rodent

activity observed in the area. They were secured in the station using wire or jolt head nails which prevented their removal from that site. Less bait was put out as activity and bait uptake declined. Bait stations were checked and re-stocked 2 out of 3 days until bait uptake reduced, and then stations were checked less frequently.

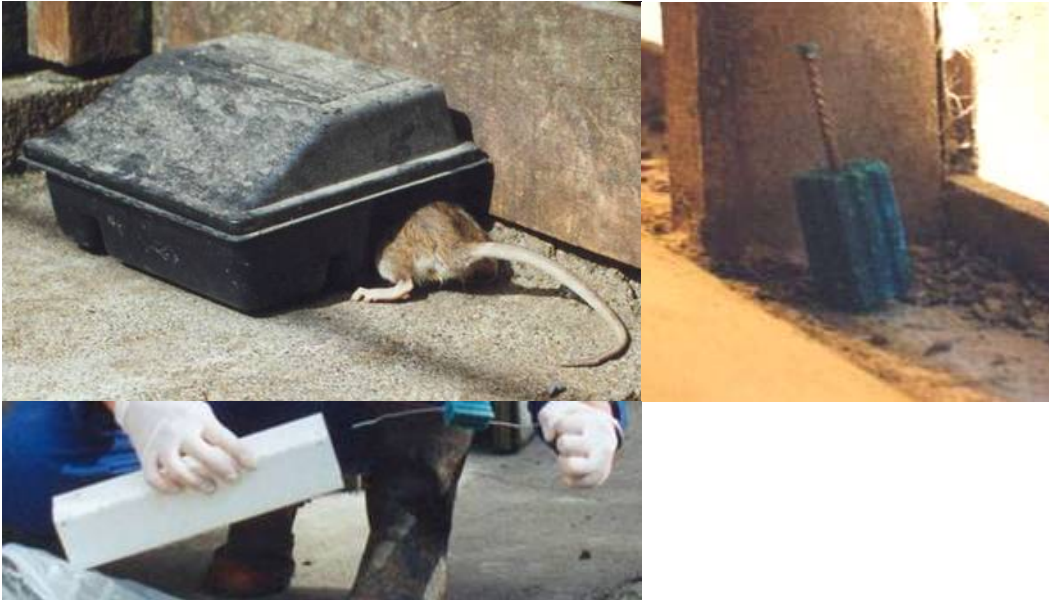


Figure 4.2 Photographs of different bait stations used on the piggery.

For each shed, bait was firstly laid in areas where fresh rodent activity was apparent. In the initial baiting period, areas with very high levels of rat activity were baited with up to one bait block per metre. The rest of the piggery was baited with one station per 100 m² inside buildings and one station per 25 m around the outside perimeter of the buildings.

4.2.5 Rat species and population structure

The Norway rat and the ship rat differ both morphologically and behaviourally. In particular, the Norway rat weighs between 120 – 580 g, is ground dwelling and tends to live close to human habitation or water sources, such as farms, landfills or ponds. In comparison the ship rat weighs between 85- 350 g, tends to live above the ground, in roofs and trees, and is less associated with human activity than the Norway rat (Long 2003).

Rats that were found dead and non-decomposed were collected for weighing and sampled for *Trichinella spiralis* testing (see Chapter 2); their weight, species and gender

were recorded. Rats that were partly decomposed were not sampled and were disposed of on the farm. Rat footprints from tracking tunnels were used to give a measure of rat size per building per week. Footprint size was assessed for each building with >5 weeks of tracking data (see section 4.2.11). One tunnel was sampled for each selected shed in each week.

4.2.6 Data analysis

The ensuing three sections describe the data analysis carried out to evaluate the trends in rodent tracking data over the study period.

4.2.7 Spatial Analysis

Digitised maps of the three piggeries were not available, so photos were digitised to create spatial data for analysis. Maps were digitised from aerial photographs of piggeries taken in 2002, at a scale of approximately 1:750. These were rectified using a programme called ER Mapper 6.4 (Earth Resource Mapping Inc., 2003), to create maps with geometric co-ordinates for spatial analysis of the tracking data. Rectifying the images involved matching physical features from the digitized photo with those on a digital orthophoto of the area containing the geometric co-ordinates from the New Zealand Map Grid. The mean R^2 error (RMS) was used as a measure of how well these physical features matched, where R^2 error <5 indicated acceptable fit. These maps were exported into Arcmap version 9 (ESRI Inc., 2005).

Shape files of tunnel locations, bait stations, buildings and piggery perimeters were added to each digitised piggery map. The shape files of tunnel location included binary data describing tunnel position; whether it was situated inside or outside, and whether it was positioned on or off the ground. The building shape file included categorical data on building type and stage of pig production per building.

Rodent activity was summarised for each tunnel for the three piggeries as a percentage of total study nights that the tunnel recorded activity. The rodent activity rate for each tunnel was used to create a map that visually displayed the persistence of rodent activity throughout each piggery over the 74 week study period. Rodent activity is a point value that relates to a single tunnel location on the piggery map. The value from the tunnel was assumed to estimate activity within a 10 metre radius of the tunnel. In order to represent this activity over the whole area, and consider different levels of

activity in nearby tunnels, the activity values had to be extrapolated to a wider area than just that of the tracking tunnel. This was done in Arcmap using “nearest neighbour interpolation”, a technique used to create values as a surface image for the whole area. The surface image is a gradient of tracking rates from the recorded values. The surface map is a representation of activity in the area, taken from the tunnel data collected in those areas.

The area serviced per bait station was estimated separately for rats and mice. As rats range further than mice, it was expected that mice would require smaller distances between bait stations in order to target the whole population in the area. According to recommendations from a professional pest control company (Pest Management Services, New Zealand) a radius of 3.6 m for mice and 9.0 m for rats for each bait station was the maximum desirable distance between bait stations to achieve adequate coverage. These distances for baiting coverage for rats and mice were simulated in ArcMap using buffer zones to map the bait coverage separately for rats and mice on all three piggeries.

4.2.8 Tracking rates – Binary data

The binary tracking rate was calculated as the percentage of tunnels that recorded the target species footprints in one sample night on the piggery compared to the total number of tunnels on that piggery. A binary result was recorded as 0 for no tracking and 1 for tracked. Changes in rodent activity were assessed over time by plotting the tracking rates separately for each piggery for rats and mice.

Tracking papers where both rat and mouse footprints were recorded in the same night were used to measure the territory overlap between species. The tracking rate from papers with overlap was plotted against tracking rates of exclusive mouse or rat activity. Correlations between single species activity and overlapping species activity were investigated. Correlations in tracking rates were analysed using the R^2 value from a scatter plot, where a value higher than 0.1 indicated a relationship between species.

4.2.9 Tracking rates – Categorical data

Intensity of rodent activity was assessed by categorising tracking papers from 0 to 4, according to the density of footprints recorded by the tracking paper (Table 4.3). Activity categories were assessed by footprint cover on the tracking papers rather than

colour depth, as depth of colour varied greatly depending on the condition of the ink pad. The clarity of the recorded print was affected by temperature and humidity as it affected the ink in the pad and accordingly how well the dye coated the subject's feet. The categorical tracking rate was calculated as the total sum of categorised values from each tunnel divided by the total number of tunnels on the piggery, multiplied by four (four was the maximum tunnel activity value), and converted to a percentage.

Table 4.3 Definitions for categories of rodent activity used to grade papers from each monitoring tunnel.

Category	Activity	Definition
0	None	No tracks of that species on the paper
1	Very light	Evidence that one animal has been present
2	Light	Prints easily distinguishable- up to 50% of paper lightly covered
3	Moderate	Prints distinguishable, over 50% of paper covered
4	Heavy	All paper covered in prints

Photographic representations of the categories of rat and mouse activity are shown in Figures 4.3 and 4.4. These figures show the gradual increase in activity from one or two visits to a very high frequency of visits by rodents to the tunnels. There was a small issue where foot prints on heavily tracked paper could not be clearly distinguished from each other which may have affected species differentiation. However, the size of the dot made by the pad was very different between rats and mice – so it could be seen what species was present, the only issue that could arise is due to mice tracking over heavily tracked rat paper.

The categorical data was analysed graphically to compare the trends shown by the categorised data compared to the binary data. Running a regression model on the categorical data was not undertaken for the following reasons:

Performing cross tabulations on some categories found that for some variables there was no data, particularly for the variable 'Week' as in some weeks there was only low activity, so no category 4 activity levels were available. Logistic regression requires that all categories in the analysis contain data.

Although the data could be analyzed using GENLOG in SAS (SAS Institute Inc., 1999-2001) for categorical data, this feature required further steps, as the data were ordered categorical data which requires an adjacent-category log-model and time constraints did not allow this path to be pursued.

The categorical data was used to create surface images in Arcmap to visually assess rat and mouse activity over time. Both rat and mouse activity was plotted on the same map. The maps were then animated on Windows Movie Maker so the whole study period could be viewed sequentially along with the current stage of baiting and season (see Appendix 4.5).

As for the binary data, territory overlap between species was examined and only significant relationships were displayed.

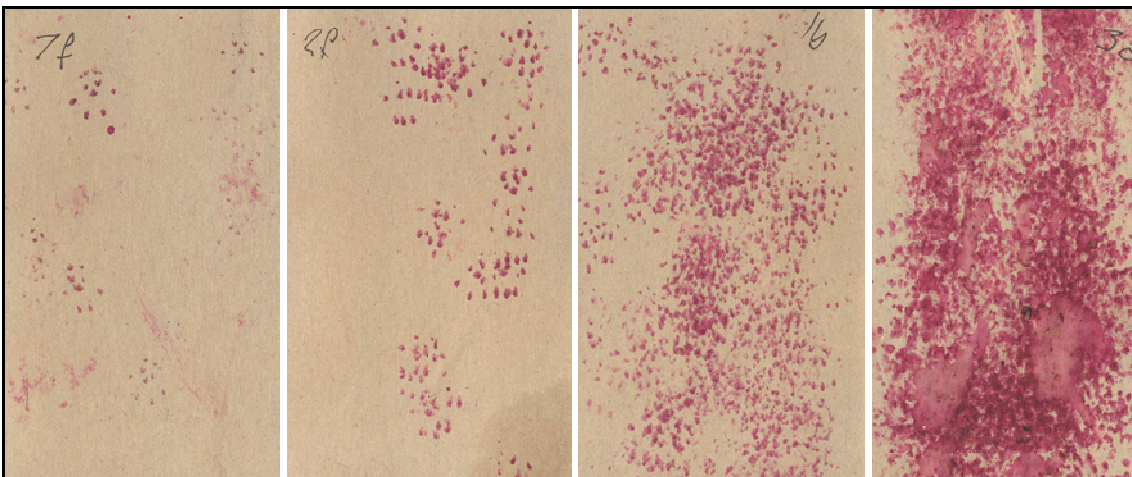


Figure 4.3. Photographic representation of categories of rat activity, from left 0- very light, 1- light, 2 - moderate and 3- heavy.

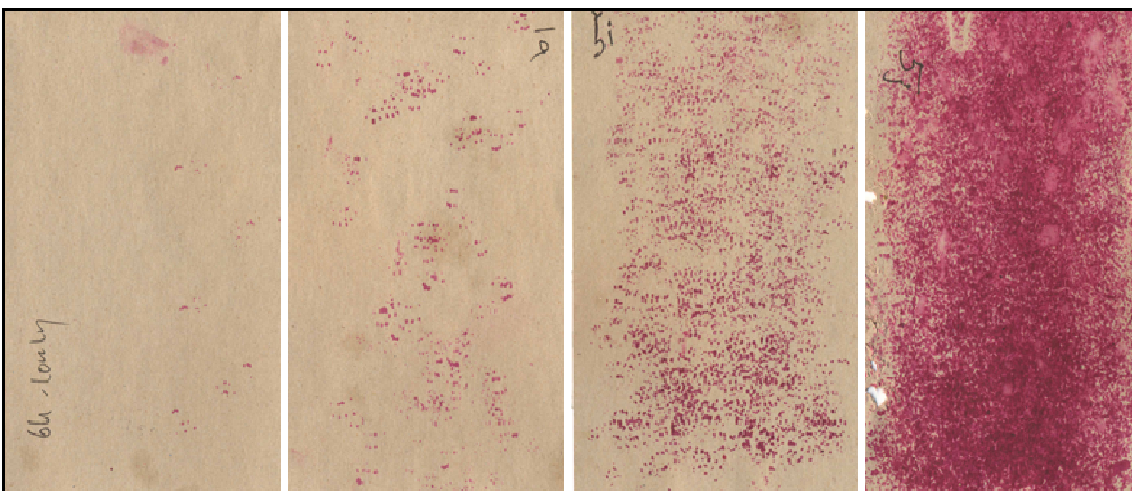


Figure 4.4. Photographic representation of categories of mouse activity, from left 0- very light, 1- light, 2 - moderate and 3- heavy.

4.2.10 Risk factor analysis

Univariate analyses were performed on all possible explanatory variables using a Pearson Chi² test in SAS version 8.2 (SAS Institute Inc., 1999-2001). Explanatory variables showing a statistically significant difference ($P \leq 0.05$) between tracked and non-tracked tunnels were considered as covariates in the multivariate analysis as described in Table 4.4. Tunnels around the farm perimeter that were not directly related to a building were not used in this analysis. This was because tunnels not directly related to a building create a bias for the ‘inside’ category as these tunnels are always outside.

Table 4.4 Data structure of the multivariate analysis involving repeated sampling from a tunnel that was nested within both a shed, and a farm. The categories of the outcome and explanatory variables involved in the multivariate analysis are also defined.

Data structure	(n)	Explanation
Sample	18	18 samples were taken over the 74 week study period
Tunnel	231	Site where activity was monitored, each tunnel was monitored for one night in each study week
Shed	24	Unique ID for each building in the study
Farm	3	Three separate farms were used for the investigation

Output Variable	Categories	Definition
Tracked	0	No evidence that species of interest was present
	1	Tracking paper showed evidence that species of interest was present

Explanatory Variables	Categories	Definitions
Week	1-74	Identifies in which of the 74 study weeks the sample was taken
Inside	0	Tunnel positioned outside the shed
	1	Tunnel positioned inside the shed
On-ground	0	Tunnel positioned above ground level
	1	Tunnel at ground level
Pig type	1	Grower pigs
	2	Breeder herd (includes farrowing pigs with piglets)
	3	No pig
	4	Mixed
Shed type	1	Fully enclosed shed
	2	Enclosed pen with access to outside uncovered pen
	3	Semi enclosed shed

The binary tracking variable was used as the outcome in a logistic regression model to investigate the relationship between piggery factors and rodent tracking rates during intensive baiting. Sometimes the ink pad dried out but where rat foot prints could clearly be seen on the dust on the paper or ink pad a '1' was recorded for rats at that tunnel. Mouse prints were unable to be clearly defined by this method. Piggery factors assessed were: the type of pig kept in the shed where the tunnel was positioned; whether the tunnel was inside or outside a shed, or above ground or at ground level; and the type of shed; differences between piggeries and between sample weeks.

This data set had a multilevel structure that involved recording repeated measurements for tunnels, grouped by buildings and by piggery (see Appendix 4.2). Not accounting for these repeated measurements made over time by sampling from the same tunnel in the same position can cause the data to become over dispersed and increase the significance of the outcome, creating falsely significant data (Hosmer and Lemeshow 2000). Logistic regression in Proc Genmod (SAS version 8.2) with tunnel nested within shed and piggery, included as a repeated effect, was used to model the logit of the probability of a positive outcome. Rat activity and mouse activity was analysed separately.

Covariates were included in the model according to the Hosmer and Lemeshow test (2000) for assessing the significance of co-variates in the model. This test involves using a χ^2 *P*-value, with a cut off of $P \leq 0.250$ to assess the difference between the log-likelihoods of two models, one with and one without the covariate in question.

The logistic regression analysis gave a proportion of activity for each species. This was plotted over time to assess the overall trend in tracking rates. Each category within a variable was compared with a reference category in the same group. For example, the effect of tracking rates over time was assessed by comparing the tracking rate in any given week to the tracking rate in the final week. In all cases the last category in each variable was the reference category.

4.2.11 Foot print size analysis

The four most defined prints were measured from each tunnel using digital vernier calipers (Kincromeas, model 2313; $\pm 0.01\text{mm}$). The sizes of the prints were measured for width across the foot, from the first to the last digit, depicted in Figure 4.5 as line

"s". Both front foot prints (shown on the right) and back foot prints (shown on the left) are in Figure 4.5.



Figure 4.5. Prints were measured across the foot from the first to the last digit, as depicted by line "s" for front feet (shown on the right) and back feet (shown on the left).

Initial scatter plots to assess trends in footprint size over time per building were performed in the statistics programme R version 2.0.1 (The R Foundation for Statistical Computing, 2005). Normality of the data set was assessed using the one-sample Kolmogorov-Smirnov test.

Further comparisons were made on all foot prints ($n= 376$), irrespective of building both over time and against the overall rat activity level for the building. It was possible to distinguish between rat prints and mouse prints, even on heavily tracked paper. However, it was not possible to distinguish between the prints of different rat species’.

4.3 Results

4.3.1 Tunnels and bait stations

Tracking tunnels and bait stations used in the study appeared to work well in a range of situations. Figures 4.6 to 4.8 summarise the tracking rates of rats and mice compared to the location of bait stations on each piggery for the full 74 week period. Activity is represented by a surface image of the percentage tracking rates for each tunnel. A tracking rate of over 40% means that rodents were detected for at least 7 of the 18 sample weeks of the study. Areas with over 40% tracking rate was considered by the investigator to be a “problem” area for rodent control. On the three piggeries the percentage of tunnels that were considered problem areas for mouse control was 13%, 29% and 27% for Piggeries 1, 2 and 3 respectively. On Piggery 2 (see Figure 4.7), three tunnels had 100% tracking rates over the whole study, which meant that in every week of the study mouse footprints were recorded in these tunnels. Problem areas for rat control consisted of only 8%, 7% and 5% of tunnels on Piggeries 1, 2 and 3 respectively. This means that rat populations were restricted to particular areas due to baiting.

Tracking rates (left-hand map in Figure 4.6 - Figure 4.8) are a percentage of total nights tracked for each tunnel and are displayed as an estimation of activity within a 10 m radius of each tunnel to give a picture of activity for the area. This can be compared to the level of bait station availability (right-hand map Figure 4.6 - Figure 4.8) provided at the intensive baiting stage on the piggery for each species. The areas serviced by bait stations vary between species due to the different distances travelled by rats and mice. Bait availability for rats is a 9 m radius from a station and for mice is a 3.6 m radius.

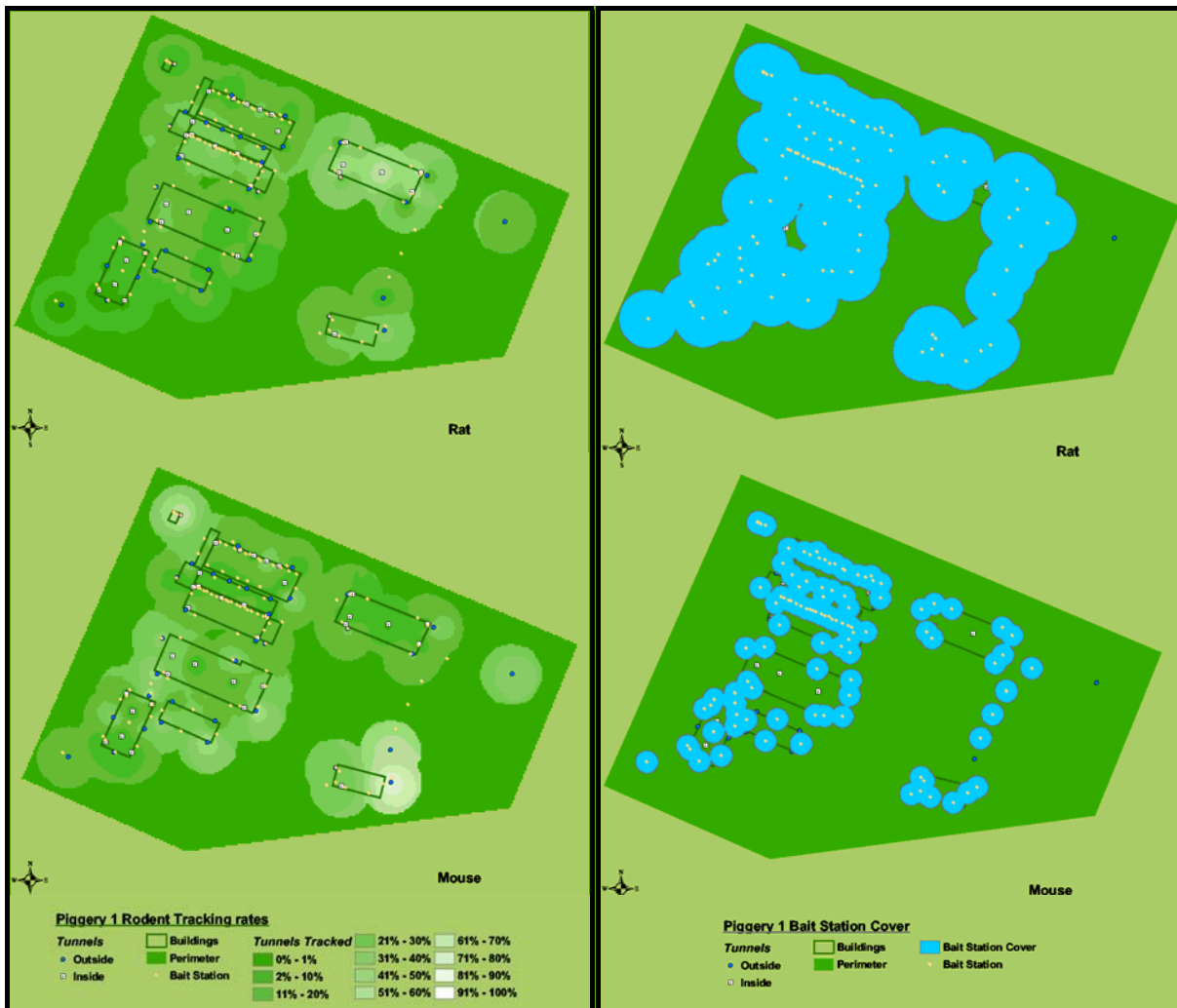


Figure 4.6. A farm map of Piggery 1 showing the perimeter of the piggery with building outlines. Tracking rates (shown on the left) are a percentage of total nights tracked for each tunnel and are displayed as an estimation of activity within a 10 m radius of each tunnel to give a picture of activity for the area. This can be compared to the level of bait cover (shown on the right) provided at the intensive baiting stage on the piggery for each species where bait cover for rats is a 9 m radius from a station and for mice is a 3.6 m radius.

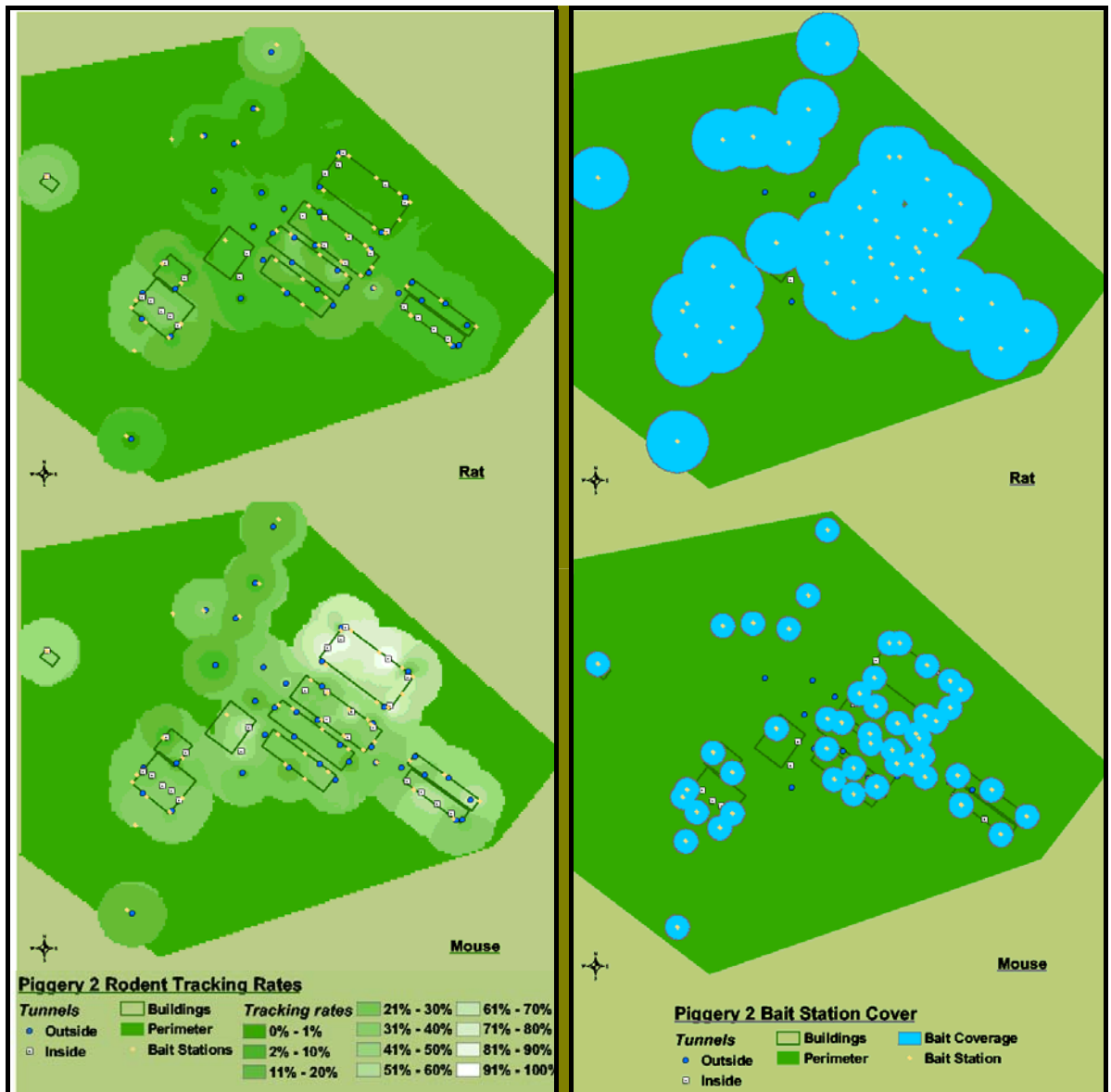


Figure 4.7. A farm map of Piggery 2 showing the perimeter of the piggery with building outlines. Tracking rates (shown on the left) are a percentage of total nights tracked for each tunnel and are displayed as an estimation of activity within a 10 m radius of each tunnel to give a picture of activity for the area. This can be compared to the level of bait cover (shown on the right) provided at the intensive baiting stage on the piggery for each species where bait cover for rats is a 9 m radius from a station and for mice is a 3.6 m radius.

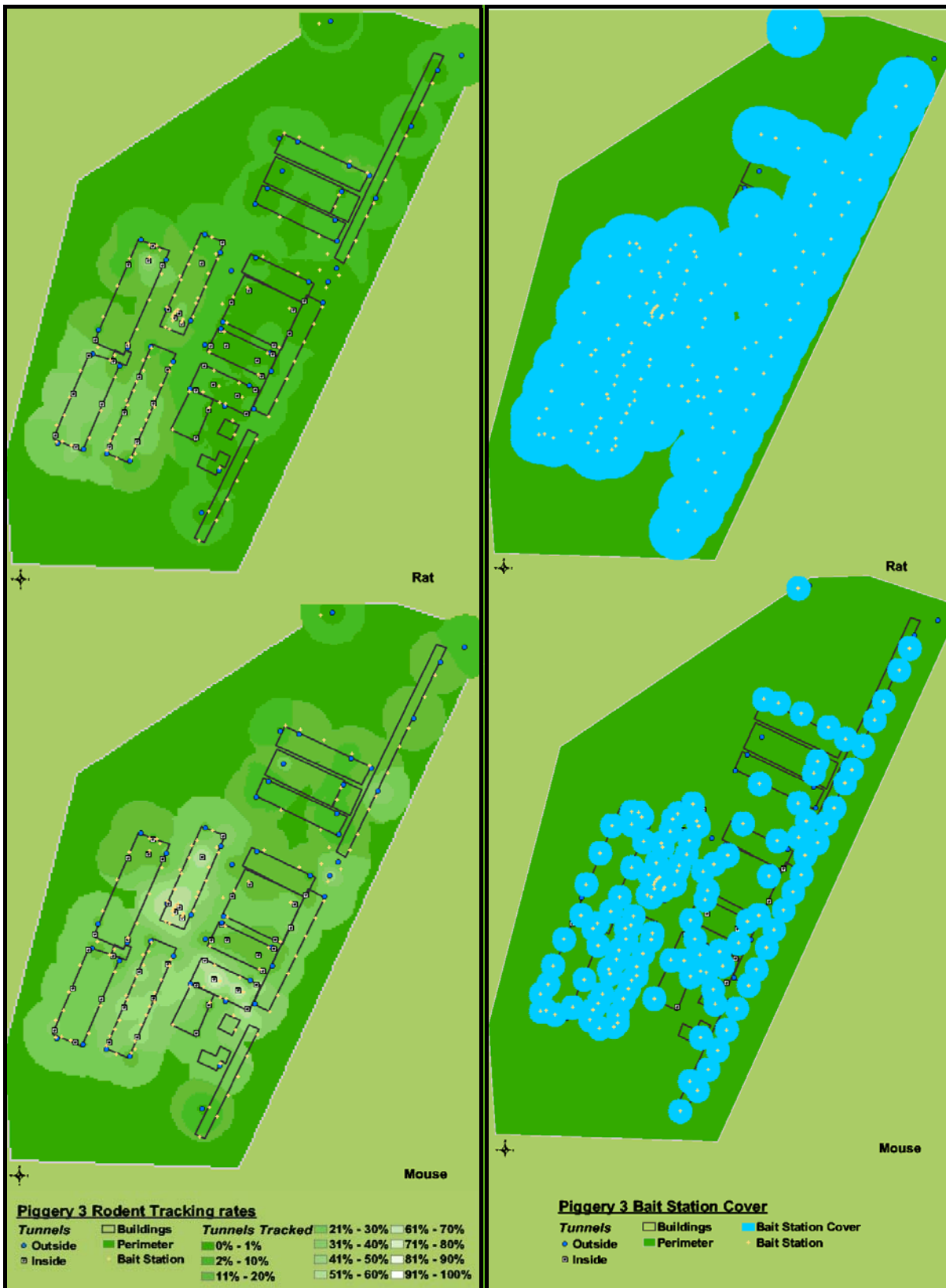


Figure 4.8. A farm map of Piggery 3 showing the perimeter of the piggery with building outlines. Tracking rates (shown on the left) are a percentage of total nights tracked for each tunnel and are displayed as an estimation of activity within a 10 m radius of each tunnel to give a picture of activity for the area. This can be compared to the level of bait cover (shown on the right) provided at the intensive baiting stage on the piggery for each species where bait cover for rats is a 9 m radius from a station and for mice is a 3.6 m radius.

4.3.2 Tracking rates

Tracking rates of rats, mice and the proportion of overlap between the two is shown in Figure 4.9 for each piggery. Tracking rates for rats and mice showed a steep decline for the first two weeks post-baiting. After this period tracking rates stagnated at around 5% for rats and 20% for mice. On Piggery 1 and 2 rat tracking rates dropped to zero at Week 10 and 43. However, on both of these piggeries rat tracks reappeared at a tunnel some stage later in the trial. The proportion of tunnels that tracked both species appeared to increase or decrease according to rat tracking rates on the piggery and showed no relationship to mouse tracking rates.

Although all mouse tracking rates follow an irregular trend, the tracking rate for rats differed widely between the three piggeries. Piggery 3 had negligible tracking rates for only 3 months of the study between Weeks 34 to 43 (over winter 2003), and then tracking rates for rats on this piggery steadily increased until the end of the study period.

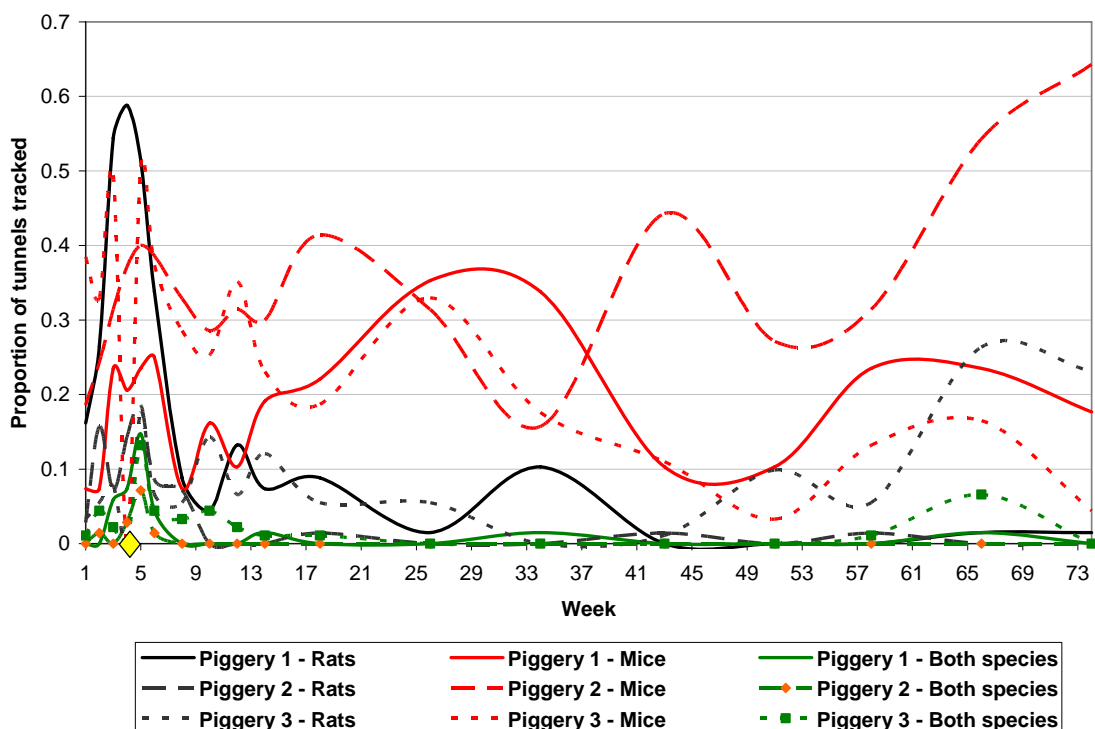


Figure 4.9. Proportion of tunnels tracked by each species, both species and proportion of overlap between species for three piggeries in the Manawatu. The commencement of baiting in week 4 is shown by the yellow diamond.

Figure 4.10 shows overall rodent activity for the study period combining data from all piggeries. Each point represents the proportion of tunnels tracked from all three

piggeries over one sample week. After Week 14, when baiting was continued by the piggery staff, rat tracking continued to decrease, but mouse numbers increased and fluctuated for the rest of the study period. Rat activity appeared to decrease to barely detectable levels over Weeks 40 to 46, during August and September (New Zealand's winter months). However, there is a resurgence of activity from Week 58 in early spring. Mouse tracking rates fluctuate throughout the study period around 15-25%. The 95% error bars show that the data does not range widely from the mean, which supports the general trend plotted on the graph.

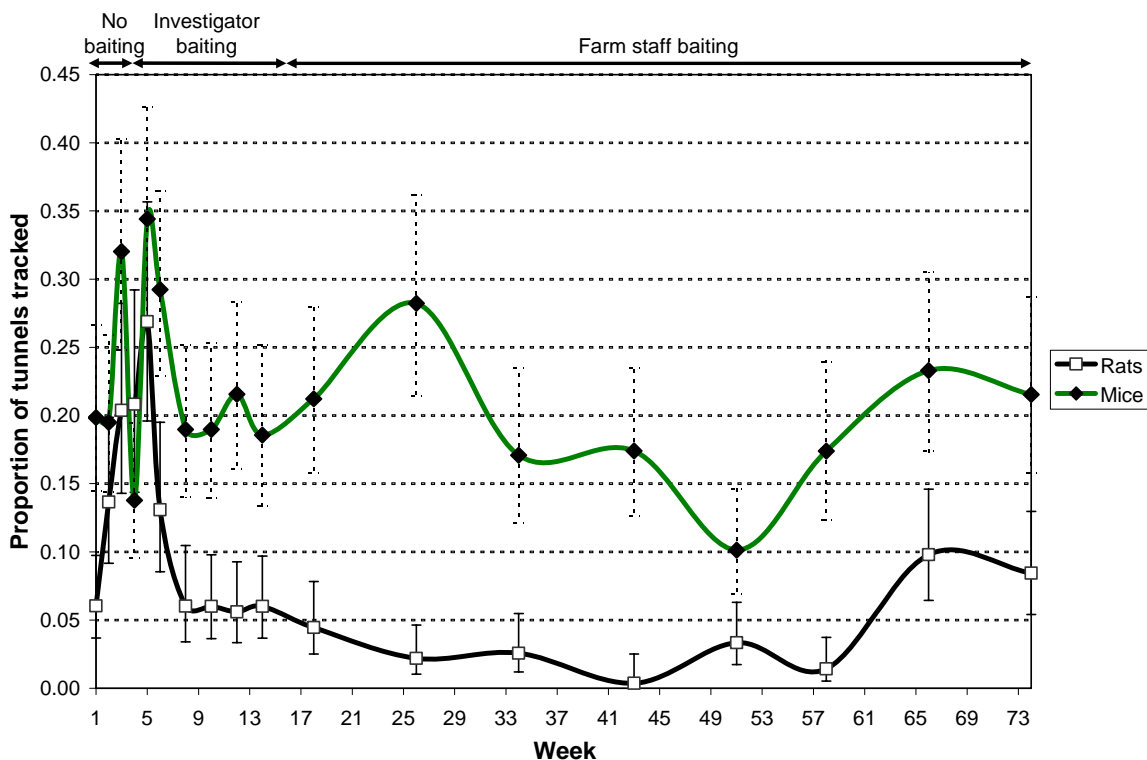


Figure 4.10. The proportion of tunnels tracked by rodents in three Manawatu piggeries from November 2002 to April 2004, with 95% error bars.

Splitting the footprints into four categories (Figure 4.11) gave similar trends in tracking rates as in the binary data. Despite the overall patterns in activity being very similar, there was a difference in activity between rats and mice. The same scoring system was used for categorising the rat data and the mouse data. This scoring system involved adding up the activity category (0 = none, 1 = very light, 2 = Light, 3 = Moderate, 4 = Heavy) given to each tracking paper in the piggery in the sample week and dividing it by four. This weighted tracking for each paper, so that papers with very few prints gave a lower activity score than papers with a lot of prints. For rats, the

categorised data set showed a lower level of activity when compared to the binary data. In mice this effect was reversed as categorised data showed a higher level of activity than shown by the binary data. This suggested that the activity level in the tunnels and behaviours around the tunnels were different for rats and mice.

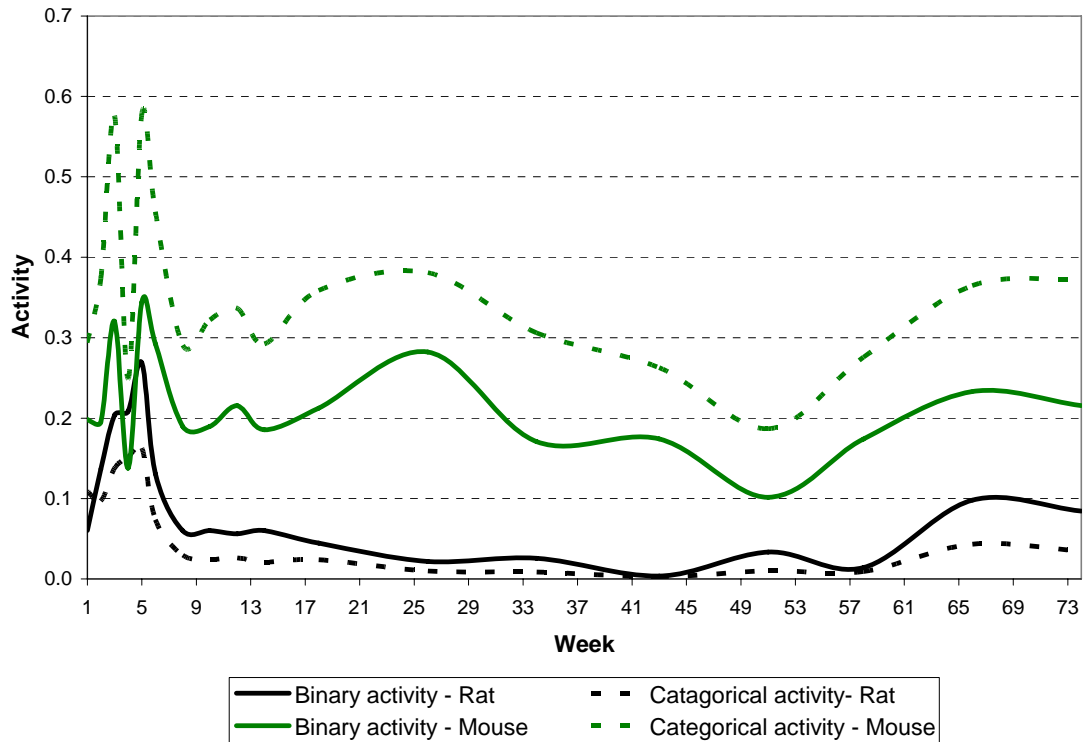


Figure 4.11. Tracking rates are displayed here as a binary result and categorical result. These tracking rates have been graphed against time for both mice and rats.

Figure 4.12 displays the correlations between the proportion of tunnels tracked by rats or mice and the proportion of tunnels with overlapping tracking records. All three piggeries showed a positive correlation between higher rat activity and the incidence of both species tracking the same tunnel (with an R^2 of: 0.67, 0.67, 0.25 for Piggery's 1, 2 and 3 respectively). Only Piggery 3 demonstrated this same trend in mice where higher numbers of mice coincided with a higher species overlap ($R^2 = 0.32$).

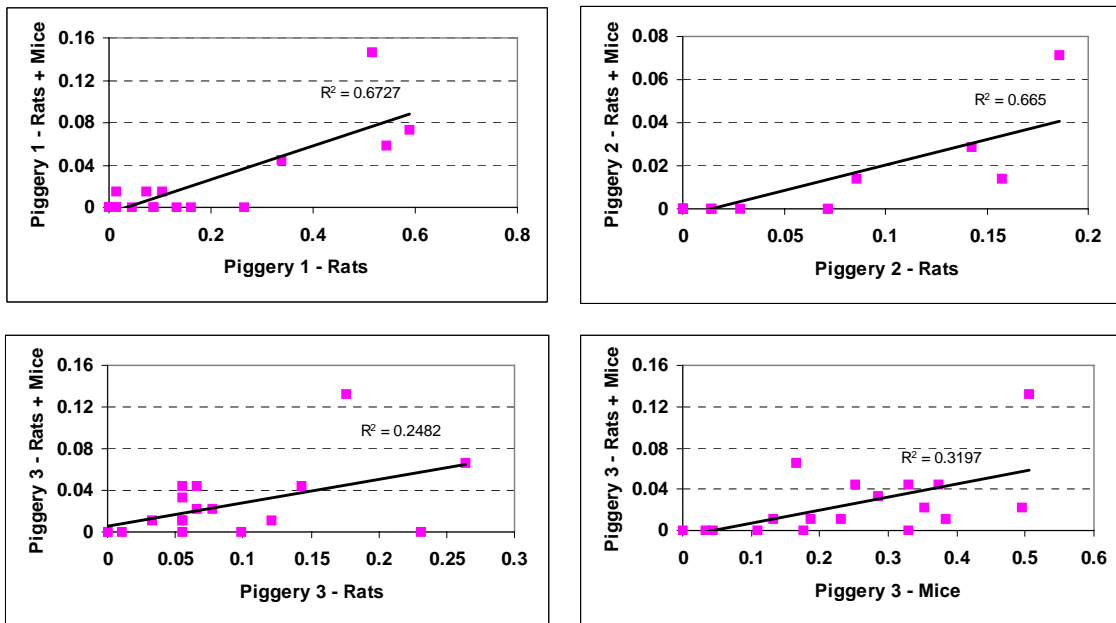


Figure 4.12. Scatter graphs comparing the tracking rates of rat, mouse and species overlap in three Manawatu piggeries.

4.3.3 Rat activity risk factors

A univariate analysis using the chi-squared test showed that all explanatory variables had a significant effect on rat activity ($P \leq 0.05$). The variables for tunnel position, above ground or on-ground, and for shed type were excluded from the final logistic regression model as they were not significant (P value was equal to 0.344, 0.961, and 0.626 respectively). The removal of these variables from the model did not significantly ($P = 0.584$) affect the fit of the model to the data.

Results from a logistic regression model assessing the effects of study week, piggery, position of tunnels and class of pig on rat activity are shown in Table 4.5. Of the eighteen study weeks, ten showed significantly different ($P \leq 0.05$) tracking rates for rats compared to Week 74, which was the reference week. Weeks 2-5 showed an increase in tracking rates of up to four times greater than the final week of the study. Baiting commenced at the end of the 4th week, and after Week 5 rat numbers appeared to decrease, however, this period of decrease was not significant ($P > 0.05$) until Week 18 – 58 when lower rat numbers became highly significant ($P < 0.001$) compared to the final week. This shows that at the end of the study period (Week 74) rat activity was higher than most of the preceding year (Weeks 8-66). The highest tracking rates (and

respectively) for both rats ($P < 0.001$) and mice ($P < 0.002$) were recorded in Week 5, which was the first week following the initiation of baiting for the study.

Overall Piggery 1 was three times more likely to have rodent activity than the reference Piggery 3, whereas Piggery 2 was half as likely to track rats as Piggery 3. Despite the very high tracking rates on Piggery 1, successful control was achieved. Tunnel position inside or outside, and which class of pig that the tunnel was positioned near also had highly significant effects ($P < 0.001$) on rat tracking rates. Rats showed a high preference for being inside buildings rather than outside. Tunnels placed outside had approximately three times less rat tracking activity than tunnels placed inside.

A highly significant result ($P < 0.001$) was found for rats tracking tunnels around grower pigs. Rats were four times more likely to be found around grower pigs than around the reference group (mixed category, which included areas with adult and grower pigs in the same building, e. g. farrowing sows with piglets). There appeared to be no real difference between rat tracking rates around pigs in the breeding herd and in areas with no pigs. These two areas were marginally significant for higher tracking rates by rats when compared to areas of mixed age pigs (farrowing sows and replacement breeder stock kept in the same buildings as grower pigs). There was no apparent effect of shed type on rat distributions within the piggeries, however this data is still presented in the table for comparison with the significant result seen in mice.

Table 4.5. Results from a logistic regression model assessing the effects of study week, piggery, position of tunnels and class of pig on rat activity. The odds ratios are given with the upper and lower 95% confidence intervals (CI) of the odds ratio.

Variable	Category	Number of observations	Tunnels		OR	lower CI	upper CI	P-value
			per category					
INTERCEPT	-				0.06	0.02	0.16	<.0001
WEEK								
	1	16	(214)		0.68	0.33	1.39	0.290
	2	34	(214)		1.76	0.93	3.34	0.084
	3	49	(214)		2.95	1.51	5.78	0.002
	4	50	(214)		3.05	1.56	5.96	0.001
	5	63	(214)		4.43	2.49	7.86	<.0001
	6	33	(214)		1.66	0.87	3.15	0.123
	8	16	(214)		0.67	0.33	1.36	0.266
	10	16	(214)		0.68	0.36	1.28	0.227
	12	15	(214)		0.63	0.30	1.31	0.215
	14	16	(214)		0.68	0.36	1.28	0.231
	18	12	(214)		0.49	0.24	0.99	0.047
	26	6	(214)		0.23	0.10	0.52	0.000
	34	7	(214)		0.27	0.11	0.68	0.006
	43	1	(214)		0.04	0.01	0.27	0.001
	51	9	(214)		0.36	0.18	0.70	0.003
	58	4	(214)		0.16	0.06	0.42	0.000
	66	25	(214)		1.18	0.73	1.89	0.508
	74	22	(214)		1.00			
FARM								
	1	201	(1188)		3.01	1.78	5.07	<.0001
	2	53	(1098)		0.49	0.28	0.87	0.0155
	3	140	(1566)		1.00			
INSIDE								
	Outside	121	(2016)		0.28	0.19	0.41	<.0001
	Inside	273	(1836)		1.00			
CLASS OF PIG								
	Grower	189	(1386)		3.99	2.20	7.21	<.0001
	Breeder	87	(936)		2.04	0.95	4.36	0.067
	No pig	38	(504)		2.02	1.03	3.95	0.041
	Mixed	80	(1026)		1.00			
SHED TYPE								
	Fully enclosed	272	(2358)		1.01	0.64	1.60	0.961
	Yard + shelter	27	(576)		1.23	0.54	2.78	0.626
	Semi-enclosed	95	(918)		1.00			

ref = The reference group with is always equal to 1.00

The upper and lower 95%CI for the reference category =1.00

4.3.4 Mouse activity risk factors

The category of ‘on-ground’ was removed from the final mouse model as it was not a significant factor in predicting mouse activity ($P = 0.467$).

The results of the logistic regression model for mouse behaviour are given in

Table 4.6. Walking through the sheds provided visual evidence of lowered mouse activity after intensive baiting was carried out, particularly where initially there were high numbers of mice. However, the logistic model showed that changes in mouse tracking rates over time were largely not significant when compared to the 74th week of the study. Weeks 3-6 were significantly different to the reference week; however the result was not consistent as weeks 3, 5 and 6 had higher mouse activity than week 74 but week 4 had significantly lower activity.

As with rats, there was a strongly significant difference in mouse tracking rates between the three piggeries. However, the opposite trends to those noted for rats were observed in mice. Overall, Piggery 1 recorded half as much mouse activity as Piggery 3 ($P = 0.003$), whilst the tracking rate for mice on Piggery 2 was 2.7 times higher than that of Piggery 3 ($P < .0001$). There was a small but significant increase in tracking rates for mice inside buildings compared to outside buildings ($P = 0.014$).

Tracking rates around grower pigs were 50% lower for mice compared to tracking rates around mixed pig areas ($P = 0.003$). Tracking rates around breeder and non-pig areas compared to mixed pig areas was not significant. There was no significant difference in mouse activity in fully enclosed sheds compared to semi-enclosed sheds. However, enclosed pens with access to outside uncovered pens showed an over 50% decrease in mouse activity compared to the reference 'semi-enclosed' shed type ($P = 0.011$).

Table 4.6. Results from a logistic regression model assessing the effects of week, piggery, position of tunnels and pig type on mouse activity. The odds ratios are given with the upper and lower 95% confidence intervals (CI) of the odds ratio.

Variable	Category	Number of observations	Tunnels per category	OR	lower CI	upper CI	P-value
INTERCEPT	-			0.43	0.25	0.74	0.002
WEEK							
	1	53	(214)	0.90	0.56	1.45	0.668
	2	52	(214)	0.88	0.56	1.38	0.582
	3	80	(214)	1.72	1.12	2.63	0.013
	4	38	(214)	0.58	0.39	0.87	0.008
	5	85	(214)	1.91	1.26	2.90	0.002
	6	74	(214)	1.50	1.00	2.26	0.048
	8	51	(214)	0.85	0.55	1.31	0.470
	10	51	(214)	0.85	0.56	1.29	0.450
	12	57	(214)	1.00	0.65	1.55	0.997
	14	50	(214)	0.83	0.54	1.27	0.392
	18	56	(214)	0.98	0.66	1.45	0.925
	26	72	(214)	1.43	0.96	2.15	0.082
	34	46	(214)	0.75	0.49	1.16	0.193
	43	47	(214)	0.77	0.53	1.11	0.164
	51	29	(214)	0.41	0.27	0.63	<.0001
	58	47	(214)	0.77	0.51	1.15	0.196
	66	61	(214)	1.11	0.76	1.61	0.597
	74	57	(214)	ref			
FARM							
	1	220	(1188)	0.57	0.39	0.83	0.0031
	2	402	(1098)	2.77	1.81	4.25	<.0001
	3	384	(1566)	ref			
INSIDE							
	Outside	449	(2016)	0.70	0.53	0.93	0.014
	Inside	556	(1836)	ref			
CLASS OF PIG							
	Grower	311	(1386)	0.56	0.38	0.82	0.003
	Breeder	269	(936)	0.73	0.49	1.07	0.109
	No pig	137	(504)	1.03	0.58	1.84	0.922
	Mixed	289	(1026)	ref			
SHED TYPE							
	Fully enclosed	666	(2358)	1.47	0.95	2.29	0.083
	Yard + shelter	142	(576)	0.49	0.29	0.85	0.011
	Semi-enclosed	198	(918)	ref			

ref = The reference group with is always equal to 1.00

The upper and lower 95%CI for the reference category =1.00

4.3.5 Goodness of fit for the logistic regression model

A graph of the residuals from the logistic regression analysis for rat activity and mouse activity are shown in Figure 4.13. The points are close together for both response curves and no unusually high outliers are present for either the rat or mouse logistic regression model. This indicates that both models fit the data well. Further support of the goodness of fit for each model is that the algorithm converged that was used to compute the models. This means that the models consistently predict the expected values given a 95% confidence interval around the expected values.

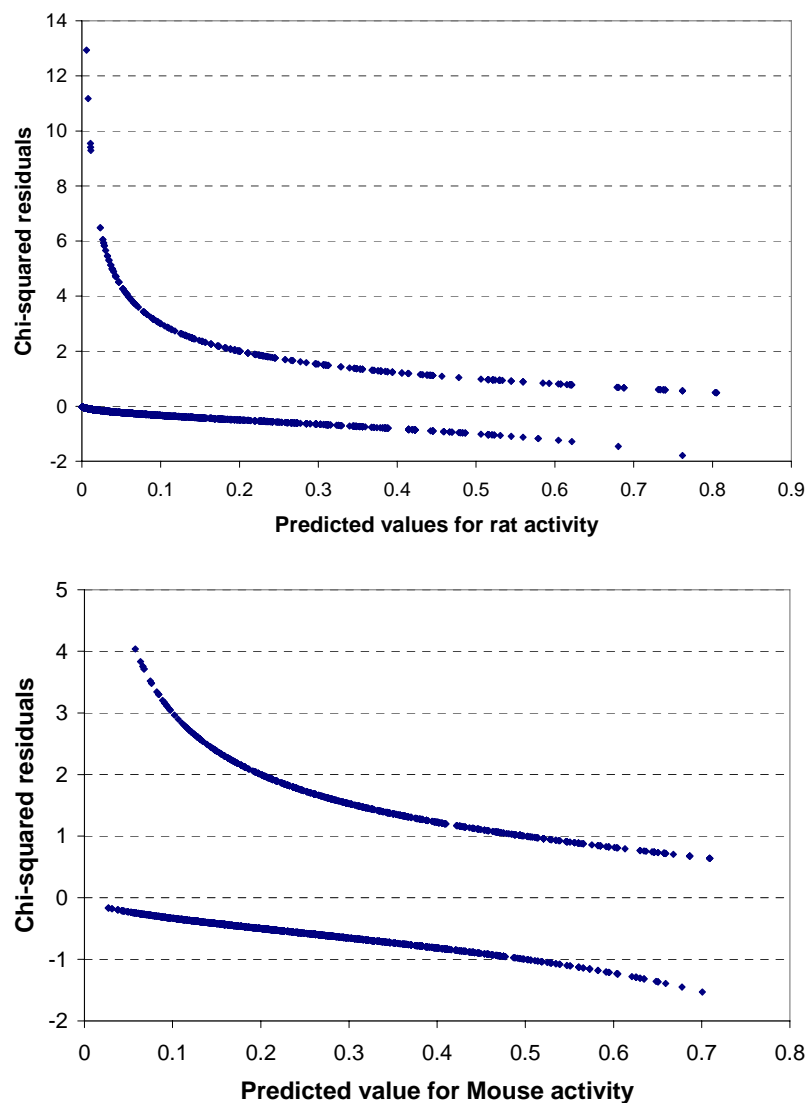


Figure 4.13. The predicted value for rat tracking (left) and mouse tracking (right) versus the chi-squared residual of the outcome variable.

4.3.6 Rat populations in piggeries

Rats found on the piggeries did not appear to be cannibalised or eaten in any way. Table 4.7 shows a summary of total number of rats collected, the average rat weight and weight range of recently dead rats found in each piggery. Appendix 4.4 shows these data in full including the species and gender for each rat where possible.

Table 4.7. Date, number, species and weights of dead rats from three Manawatu piggeries.

Piggery	Date	Number	Species' Identified	Av. Weight (g)	Weight range (g)
Piggery 1	Dec 2002 - Feb 2003	17	Ship rat only	139.1	85-176.6
Piggery 2	Dec 2002 - Jan 2003	5	Ship rat and Norway rat	205.3	53-452.8
Piggery 3	Dec 2002 - Feb 2003	8	Ship rat and Norway rat	235.4	90-509.2

A variety of methods were used to analyse rat footprint size. Overall the footprint data were normally distributed ($x = 15.63$, S.D. = 2.31), with a non-significant p-value for the one-sample Kolmogorov-Smirnov test for normality. Scatter plots of footprint data from individual buildings showed no plausible trends (see Appendix 4.3).

There were no trends (Figure 4.14) in overall footprint size over time ($R^2 = 0.0001$). Fewer measurements were made due to lower rat numbers between Weeks 20 and 50 resulting in the narrow spread of rat footprint size over this time.

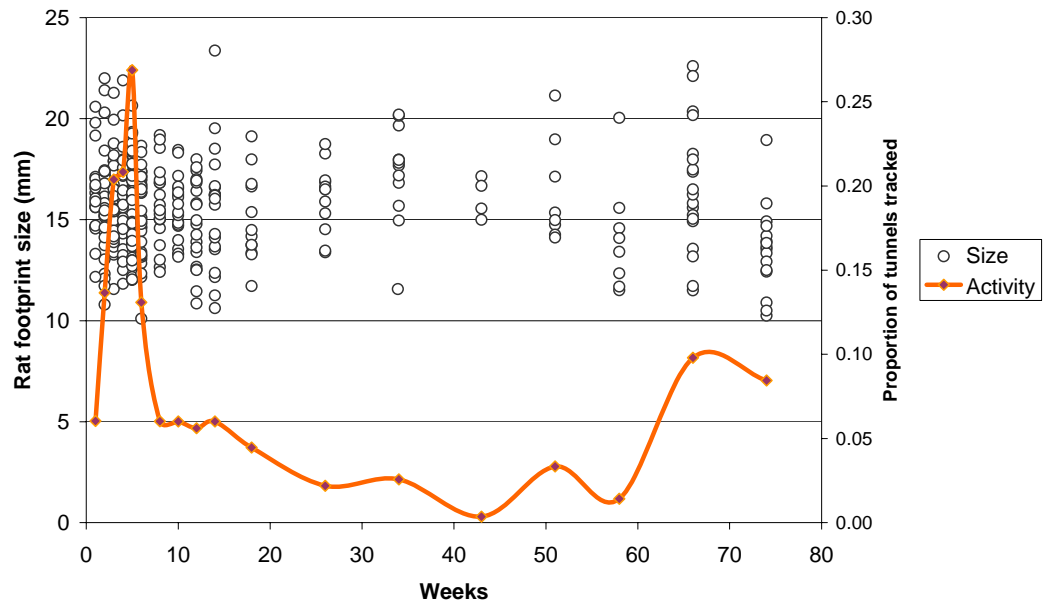


Figure 4.14. The size of individual rat footprints (mm) over 74 weeks, along with overall rat tracking rate.

There was no relationship between rat footprint size and rat activity irrespective of time, as the scatter plot appeared to be evenly spread on both axes (see Figure 4.15).

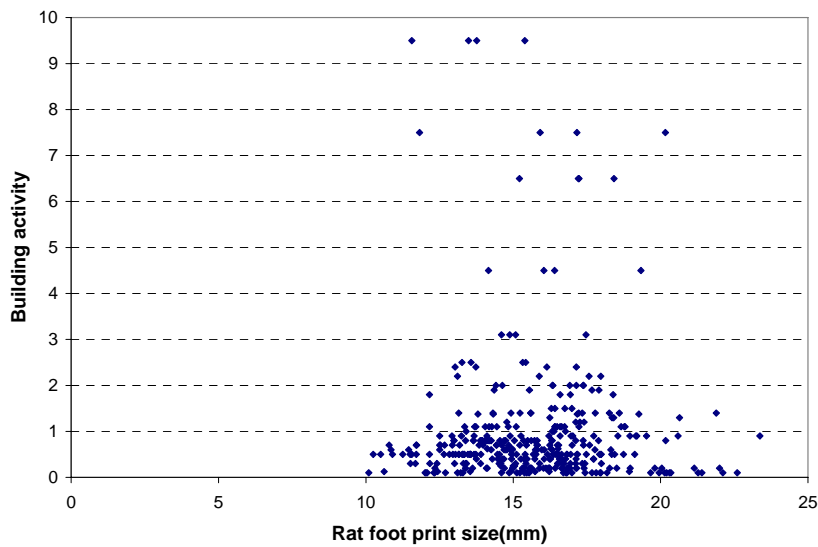


Figure 4.15. Scatter plot of rat footprint size against the average activity level observed in that building at the time the footprints were recorded.

4.4 Discussion

A general linear logistic regression model was used to assess the affect of intensive poison baiting on three commercial piggeries in the Manawatu region. Baiting appeared to successfully reduce the presence of rats on two of the three piggeries, but on none of the piggeries was mouse activity contained by the baiting program over the length of the study. Rodent activity was found to differ in buildings between those housing grower pigs and other production stages of pig and also between the inside and the outside of sheds. There was some suggestion from the data that high population activity in either species excluded the other, and at low mouse numbers rats would start to enter their territory.

Rat and mouse tracking rates declined from week 5 to 8 illustrating that the baiting program installed on the piggeries was effective over this period. The observed decline stopped when baiting switched from intensive baiting to maintenance baiting, even though tracking rates were still around 20% in mice and 5% by rats. This reduction of tracking rate decline suggested that the intensive baiting period was not continued for long enough. Intensive baiting should have been maintained on the study piggeries until no rodent sign was recognised. Animals that did not react to baiting should have been carefully kill-trapped using a well thought out plan (Corrigan 2001). Traps need careful placement and pre-baiting to be effective. However, once staff baiting commenced overall rat numbers began to decrease again. Zero tracking rates for rats in Piggery 1 and 2 were achieved and maintained for most of the second half of the study.

Reinvasion may have been the cause of very occasional tracking by rats in monitoring tunnels after a period of no tracking on Piggery 1 and 2. Consistent rodent control was not achieved on Piggery 3. Any renewed evidence of rat activity at individual stations needs to be noticed promptly and action taken as soon as possible to eradicate the pests. Persistent infestations may require using another type of bait for a period and further efforts to identify and eliminate factors present that may be attracting them to that area.

Effective rodent control requires attention to the target species dietary preferences, their potential neophobia, social interactions, and habitat structure, as these can affect an individual's exposure to bait and levels of bait consumption (Pelz and Klemann 2004). Ready access to food on most piggeries increases the challenge of effectively using

anticoagulant baits. Baiting closer to rodent nesting sites than to other available food sources and baiting where high activity is noted as important (Corrigan 2001).

Bait specifications from the Confrac retailer (Bell Laboratories, Ltd., 2002) recommend continuing a steady bait supply to rats for at least 10 days, and mice for at least 15 days, or until activity ceases. In our study, the minimum period of time from baiting to tracking no rats was 42 days for Piggery 2. This result is vastly different to that described by the bait manufacturers as baiting had to be sustained for much longer than 10 days to control rats. In a study on different levels of bait availability in different baiting operations the average time to a 99% bait-take level was 20-40 days (Thomas and Taylor 2001). This further supports that our baiting program should have continued intensive baiting for longer. Under the circumstances of the study, this would only have been possible with more people to bait and monitor the farms. If the programme was to be used on other piggeries, farmers would have to be more involved in the intensive baiting stage.

During this study, all three piggeries appeared to have comprehensive bait station cover for rats around buildings, however bait stations for mice were localised and appeared sparse in some areas. It is important that fresh bait is well secured in areas that encourage feeding by rodents and discourage exposure of poison to non-target animals. Bait uptake is likely to be maximized in areas where rats and mice tend to forage or defecate and where the rodent can hide from human activity. Lack of bait supply due to the location of bait stations for mice, was particularly evident for Piggery 2. However, in repeated studies on baiting carried out for conservation purposes, a distance of 50 m was found to be adequate to kill off all rats and mice in an area (Thomas and Taylor 2001). This was not found to be true in our study, possibly because mice (and rats) in piggeries do not need to forage for feed over any distance as they probably do in native bush. A good rodent control programme should target both rats and mice but our study did not achieve mouse control on any of the piggeries. It is not expected that mice can be completely controlled, but realistically numbers should be sustained at very low levels.

Population dynamics within each rodent species appeared to affect the success of the baiting program. Although rat numbers decreased with staff baiting from Week 18, mouse numbers increased. This increase in mouse tracking may have been related to

lowered rat activity allowing mice to access new areas. This was expected as Norway rats have been known to exclude mice from some habitats and our study suggested mice do not normally live in areas with high numbers of rats (Moors 1990), which is also supported diagrammatically by Appendix 4.5. Contrary to this, there was no direct relationship found in any piggery between rat and mouse tracking rates (Figure 4.12). Factors affecting the increase in mouse numbers compared to rats could be that farm staff may have prioritised baiting to areas where rats were known to be a problem, and that bait station cover may have been inadequate for mice.

The changes of the seasons may have influenced tracking rates. The variable ‘inside’ could have been affected by wet weather, as animals may not frequent outside tunnels when it is raining, which would create higher tracking for inside tunnels on a wet sample week. The decreases in tracking rates noted over winter and subsequent increase in spring of rat numbers on Piggery 3 is suggestive of seasonal variations, rather than any real effect of baiting. As no control site was available for comparison during the trial, the effect of baiting could not be compared to the natural seasonal variations in the population from 2002 till 2004.

Piggery 3 was larger than the other two piggeries and proved difficult to bait. This poor level of control may be attributed to the piggery having several different ‘centres’ of rat activity as well as hosting both rat species in the piggery. Bait uptake for different species may be affected by bait location, for example, if bait is only laid at ground level it may control Norway rats if they are present, but is unlikely to control ship rats. Ship rats have proven difficult to control in conservation areas (Innes, Warburton et al. 1995). Ship rats may be more complex to control as it is difficult to place bait in the roof areas where they live and have small home ranges ($\leq 17\text{m}$) (Leung and Clark 2005). Conversely, Norway rats tend to live in the ground which may make their presence easier to detect, and potentially easier to bait (Thomas and Taylor 2001). In this study, the first rats to be noted after the week of zero tracking on Piggery 3 were at ceiling height, where grain accumulated due to the feed lines. This location suggests that the rats were ship rats that had not been controlled by the baiting strategy. Poor control in one area could allow reinvasion of areas where control has been achieved. Piggery 1 appeared to only have ship rats on the property, and poison baiting managed

to control the population efficiently. Similarly, Piggery 2 had both rat species present on the piggery and again control was effective.

New Zealand piggeries have a wide range of building types creating challenges for creating safe bait placement away from pigs. Further to this, it would seem that general staff attitudes are such that rodent control is an unfavourable task with low priority. Success of baiting to control rats has been found to be strongly related to farm staff compliance (Endepols, Klemann et al. 2003). Their study found that farms which achieved total eradication of rats complied with at least 81% of the prescribed control plan, compared to farms where rats persisted which complied with less than 51% of the plan.

Findings by Stojcevic (2004) suggested that farms with low sanitation had more rats. Damaged buildings and overgrown vegetation around buildings encourage rats as vegetation around buildings provides food, water and cover. It was noted on Piggery 3 that Norway rats did not reinvade an area that had previously sustained very high rat activity once staff had cleared away debris and rubbish. Spilled feed, dried excrement, dead pigs, rotten sacks and old or unused equipment should all be removed from the farm as they create areas for rats to feed, nest and shelter. Similarly, on Piggery 2 areas of poor sanitation, such as where old feed sacks and excrement were allowed to build up, mice seemed particularly difficult to control.

The method of recording mouse and rat activity using tracking tunnels worked well in most cases as the ink pad and papers resulted in clearly distinguishable foot prints for analysis. In some areas, the tracking tunnel method was not suitable to assess activity for the following reasons. Tunnels could not be placed in warm areas, such as near heat lamps as the ink dried out and foot prints were not able to be recorded. In some cases, rat footprints were evident in the dust on the ink pad and paper, but not on the paper, because the ink was too dry. The data collected from tunnels in these areas would not accurately represent the activity present. In particular, for mice as their smaller print size was not obvious in the dust compared to rat prints, so the presence of mice in such cases could not be substantiated.

Rat activity may have been under-estimated in some areas. Rats may not use tunnels outside of their usual paths of activity (Corrigan 2001). This was observed in Piggery 3

where, in one group of semi-enclosed sheds, up to six rats at a time were observed during the 2002/2003 summer lying at the backs of pens. Obvious evidence of rat infestation was also apparent in these areas in the form of holes in the ceiling with grease marks left from the rat's passage. Rats were rarely tracked in this area as tunnels could not be placed where rats were observed due to space restrictions and so tunnels were either at the front of the pens or on the ground. In this area, tunnel monitoring did not indicate the true activity of rats.

The correctness of categorising tracking papers into four activity categories to estimate activity was confounded by the following factors. The peanut butter used as bait in the tunnels was applied with a modified sealant gun. The imprecise flow rate from gun did not allow for accurate or even application of peanut butter into the tunnels. Rodent activity in the tunnel may have been influenced by the amount of peanut butter. Larger amounts of peanut butter may have created higher activity in a tunnel as rodents come back to feed. Activity can also be affected by age and gender in rats as female and juvenile rats were found to make more frequent visits to feeding sources than males (Inglis, Shepherd et al. 1996). For these reasons, it is likely that categorising the tunnel data according to print density to estimate activity would be biased towards juveniles and females. Consequently, higher activity levels in spring could have been influenced by juveniles (King 1990).

Initially the data were assessed without allowing for the hierarchical nature of the data set, such as the clustering at the shed and farm-level. This resulted in all predictor variables appearing highly significant. Where clustering is present in a data set and is not accounted for, falsely significant effects of predictor variables may be found (Panageas, Schrag et al. 2003). Accounting for clustering of tunnel data at the shed and farm-level by including a nested effect, and accounting for recurring sampling over time by adding a repeated effect presented a final model with a better fit than when clustering was not considered.

An issue with the method of data collection was the unknown range over which a rat travelled, thus the collection method did not distinguish between one very active rat and several visits by one rat. Tunnels were set at less than 50 m apart in most cases in our study. It is likely that confounding occurred due to a double up of tracking, where rats have tracked more than one tunnel as 50 m was less than the average distance travelled

by rats from their nests. Accounting for data clustering by shed would have helped alleviate this problem. A method used in an Australian study (Leung and Clark 2005) was to use live-trapping and radio- and spool-and-line tracking to assess the population in the piggery and estimate the home range of the rats in the piggery. Mark and recapture studies were proposed and investigated as part of this study, but it was thought that they would not yield sufficiently useful data in the time frame possible to be worthwhile.

A further issue of the study was the use of rat activity to investigate areas of rat persistence whilst baiting. Rat activity is expected to be affected by baiting, and so levels of baiting should also have had a direct affect on areas of rat persistence. However, the effect of baiting on rodent activity was only considered in the logistic regression analysis as the change in rat activity over time once baiting had commenced. Baiting was not entered as a variable in the model. Different ages and species of rat alter in their feeding behaviour, thus effecting bait uptake, and also the appeal of the peanut butter in the tunnels. Looking at preferential areas of rodent activity within the piggery without breaking the analysis into stages of baiting, or even pre and post-baiting could have adversely affected the clarity of the results. Furthermore, places that are difficult to access with bait are also more likely to be suitable for rat habitation as they are away from human activities.

The analysis of footprint sizes to assess changes in the rat population over the study period found no trend in footprint size over time. This suggests that throughout the study period rats of different sizes had access to the tunnels. In situations where some rats are dominant and guard food sources it is expected that younger rats would not have access to the food source (Calhoun 1963). In this study, the tunnels were out all night, which would give ample time for the tunnel to be visited by a range of individuals. Further more the steady supply of food available in the piggeries would make it likely that animals would not need to guard food sources. On Piggeries 2 and 3, both species of rat were present. The size difference between the two species could have confounded the measurements, if both species had access to the same tunnel. This is unlikely however, as the two species are often exclusive (King 1990).

Using a binary outcome variable for analysis resulted in larger sample sizes in each variable for regression analysis. It also ensured no missing values were present as would

have occurred with a categorical outcome variable. This simpler outcome variable allowed logistic regression analysis to be used to build a robust model that assessed risk factors for rodent activity around buildings. However, the binary outcome potentially under, or over estimated true activity and this should be acknowledged when interpreting the results. Although the binary outcome did not account for very high or very low tracking activity in the tunnel (as does the categorical outcome), it would appear that tunnel activity from the density of the recorded footprints is confounded by several factors such as age, amounts of peanut butter used and gender (King and Edger 1977; Inglis, Shepherd et al. 1996).

This study found intensive poison baiting followed by regular baiting significantly reduced rat infestations on three commercial piggeries in the Manawatu. Follow-up baiting by farm staff on two of the three piggeries maintained rats at very low numbers for the duration of the study. The lack of continuous baiting control achieved on the third piggery was attributed to issues related to staffing and to having more pigs and building space than either Piggery 1 or Piggery 2. The presence of mice was reduced by the baiting programs, but consistent low mouse numbers were not achieved. Rodent species', how they were distributed in the piggery and piggery sanitation appeared to influence the effectiveness of the baiting program. This suggests that baiting techniques in piggeries need to be modified to accommodate for different rodent species and changes in rodent populations when one species is eradicated from the piggery environment. Furthermore ongoing control can only be achieved by making piggeries less favourable environments for rodents.

5 Quantitative risk assessment for exporting fresh chilled pork products

5.1 Introduction

Trichinella spiralis is a zoonotic parasite and the most common aetiological agent of the food-borne disease trichinellosis. The parasite's potential to cause disease in humans has created adverse effects on the international trade of fresh meat from endemic countries (Gajadhar et al., 1997; Gajadhar and Gamble, 2000). Trichinellosis is a notifiable List B disease as determined by the World organisation for animal health (OIE) (Roberts et al., 1994). *Trichinella* has an unusual life cycle as it develops in the same host from infective first stage larvae (L1) through the adult stage and back to the infective L1 stage (Bowman et al., 2003).

Poor food hygiene, and practises such as feeding meat scraps to livestock, delayed carcass disposal, and the exposure of livestock or feed to rodents and other wildlife can promote the life cycle of *T. spiralis* in the domestic environment (Ortga-Pierres et al., 2000; Pozio, 2000). *T. spiralis* can infect a wide range of mammalian hosts making eradication of the parasite difficult as several different pathways may be available to continue its life cycle (Enemark et al., 2000). *T. spiralis* is well adapted to synanthropic hosts such as rats and pigs (Schad et al., 1987).

Epidemiological studies have demonstrated a link between trichinellosis and the consumption of improperly-cooked pork infected with ≥ 1 larva per gram of *T. spiralis* (Bowman et al., 2003; Gajadhar and Gamble, 2000; Murrell and Pozio, 2000; Ortga-Pierres et al., 2000).

5.1.1 Risk assessment

Risk is defined as the possibility an event that compromises human or animal health will occur. A food safety risk assessment is one part of a systematic procedure of risk analysis that identifies adverse impacts arising from a process (SMAS project site, 2005). Risk assessments in food safety are a recognised negotiating tool for international trade (Foegeding, 1997). According to the international animal health code system this procedure involves identifying the risk, assessing and managing the

risk, and communication of the procedure so it is readily auditable (Murray, 2004). Risk assessments may be either qualitative, where risk is ranked using descriptive categories; or quantitative, where numerical expressions are used to define risk and the uncertainty around that risk (World Health Organisation, 1999). Models can be used to simulate potential risk situations and ultimately the overall risk of food being contaminated.

5.1.2 Process of a risk analysis

The components of the risk analysis outlined below, follow those set by the World Organisation for Animal Health (Murray, 2004).

Hazard identification

The hazard in this risk assessment is *T. spiralis* infection. The question that the analysis aimed to answer is: What is the likelihood that a randomly selected pork product eligible for export into the Singapore market has a larvae burden of 1 LPG or greater of viable *T. spiralis*? More specifically, the hazard was defined as a product with a larval burden of ≥ 1 larva/g of viable *T. spiralis* as such a larval burden is sufficient to cause clinical disease in humans (Gajadhar et al., 1997). Effects due to intensity of infection by *T. spiralis* are not considered further. Infective larvae are ensheathed first stage larvae (L1). Larvae can remain viable for at least two weeks at ambient temperature (Jovic et al., 2001; Oivanen et al., 2002) and at 4°C for six weeks. Larvae at 4°C are tightly coiled and viable in larval recovery studies by Gamble (1999). These studies support that chilling does not affect the parasites viability. Viability is lost after exposure to temperatures below minus 18°C for more than a week or over 77°C for 30 seconds (Bowman et al., 2003; Kapel, 2000; Malakauskas, 2002).

Risk assessment

The risk assessment is a sequential process of evaluating the risk of the hazard occurring throughout the production system (Australian Government - Department of Agriculture Fisheries and Forestry, 2004).

Release assessment

The first step of the risk assessment was the release assessment which estimates the risk of the hazard being present in the product when it leaves the exporting country. This step was the main focus of the model.

Exposure assessment

The second step in the model was the exposure assessment. This section evaluates the risk of the hazard being imported and still viable once the product has been prepared for consumption. The model further uses the output of the exposure estimate to calculate the annual risk of exposure. The annual risk of exposure takes into consideration the number of units consumed by an individual per year. The annual risk of exposure differs from the exposure estimate because the outcome of the exposure estimate does not consider the impact of multiple chances for contracting infection over a time period.

Consequence assessment

The consequence assessment involves the significance to the importing country if the hazard was to infect local production systems. This risk assessment does not include a consequence assessment because Singapore does not have a domestic pig herd as all their pork and pig products for the consumer market are imported. Consequently, there is no possibility of the parasite infecting local production systems.

Risk management and risk communication

Risk management involves identifying and controlling risks in the production system. Risk communication is important throughout the assessment to ensure the process is transparent to all involved parties, such as the importing country's food safety regulators.

The risk was first estimated with consideration of all domestic production types (unrestricted estimate). This risk was then compared to five different management strategies (restricted estimate) to assess whether they would reduce this initial risk estimate.

5.1.3 *T. spiralis* in New Zealand

Approximately eight species of *Trichinella* have been defined worldwide, but only *T. spiralis* has been recognized in New Zealand (Pozio and Zarlenga, 2005). Four cases of human trichinellosis have been recorded in New Zealand, the first in 1931, and the second in 1964 (Cairns, 1966; Mason, 1978). The most recent human cases of trichinellosis occurred in 2001 in Whangamata and resulted in two people being

hospitalised. These cases were traced to an infected non-commercial piggery (Thornton and King, 2004).

In New Zealand there is a graduating scale of piggery management, from small holdings that keep one or two pigs to finish off food scraps, through to commercial business operations where large numbers of pigs are professionally reared for consumption. Biosecurity standards tend to improve as piggeries become more commercialised. Commercial piggeries have been routinely monitored for *T. spiralis* at slaughter since 1983 by the Ministry of Agriculture and Forestry (MAF) (Paterson et al., 1997). Up to 600 culled breeding sows are tested per year from abattoir sampling. This sampling frame continued over time gives a 95% probability of detecting infected animals at an annual period prevalence of 0.5% (Clear and Morris, 2004). No cases of trichinellosis have originated from commercially produced New Zealand pork, or pork products.

Over the last 40 years sporadic cases of porcine trichinosis have occurred in 27 pigs, all reared on non-commercial farms (Cairns, 1966; Mason, 1978; Clear and Morris, 2004). These positives have created perceived risk of trichinellosis from New Zealand pork (van Knapen, 2000; Pozio and Zarlenga, 2005). Under present legislation all pork for export from New Zealand is tested for *T. spiralis*, which is expensive in both time and money. This has hindered New Zealand's ability to export pork and pork products.

5.1.4 Quantitative risk analysis for New Zealand pork

This study aimed to estimate the risk of disease from *T. spiralis* to a person eating a typical amount of New Zealand pork in a country such as Singapore, which does not have its own domestic pig industry. Singapore was used here as the destination for the purposes of developing this quantitative model. This chapter describes a generic quantitative model for assessing the risk of the movement of a food borne pathogen in meat products between countries. The model was conceived to address the concerns over the un-quantified risk of *T. spiralis* in New Zealand pork.

5.2 Materials and Methods

5.2.1 Risk assessment model

The model used data to describe the probability of *T. spiralis* being present and infectious in the system at the end of each step from production in the piggery to the

final edible product. These steps are summarised in Appendix 5.2. A probability is a number, or distribution of numbers, between 0 and 1, where 1 represents that the event is certain to occur, and 0 represents the event never occurs.

5.2.1.1 Stage 1: Release assessment

The aim of the release assessment is to estimate the likelihood of entry (LE) of a randomly selected portion of pig product exported to the Singapore market being infected with at least 1 larva/g of viable *T. spiralis*. The release assessment is estimated from a series of steps, from selection of a pig for export, to the arrival of the pork product into Singapore. Each step has its own probability or likelihood of 1 larva/g of viable *T. spiralis* being present. These steps are outlined in Figure 5.1. Where the probability is calculated the equation is shown, otherwise the probability is single input value. The resulting LE estimate will be a probability distribution.

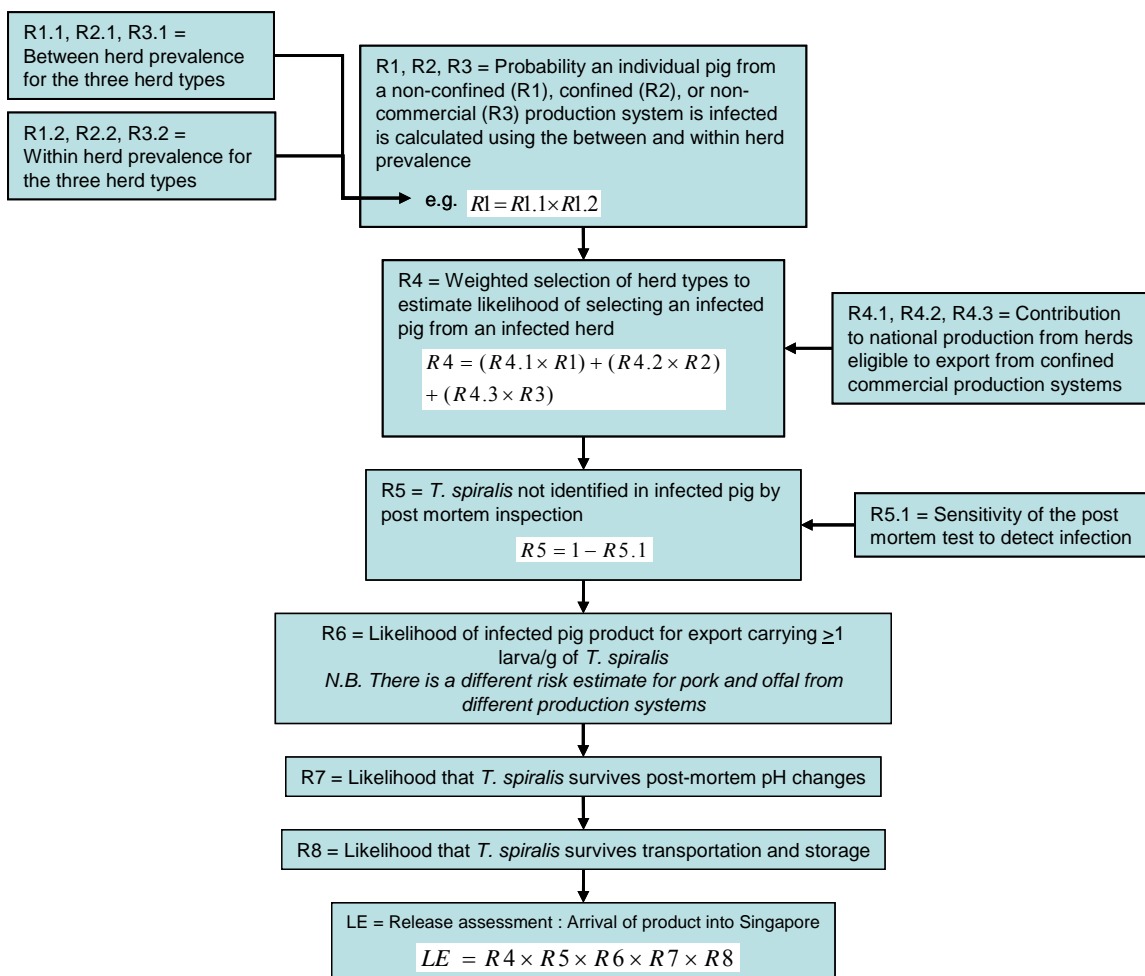


Figure 5.1 The release assessment is outlined from selecting a pig to the arrival of the pork product into Singapore. Each step represents the effect that event is likely to have on hazard. Where the step is calculated the equation is shown, otherwise the step is an input value.

Steps in the model contributing to the estimate of LE are named R1, R2, through to R8. Some of the steps were input values and some were calculated using additional data, which were labelled as sub variables (R1.1, R1.2, R2.1, R2.2 etc.). Model inputs were entered as either single values or distributions.

Four different types of distributions were used to model different types of data in the model. These were a Beta distribution, a PERT distribution, a uniform distribution, and a triangular distribution (Vose, 2000). The Beta distribution gives a value between 0 and 1 that accounts for uncertainty around the occurrence of an event in relation to the sample size and the number of successes. The parameters for defining the Beta distribution are:

$$Beta = (s + 1, n - s + 1)$$

s = number of successes (or positives)

n = sample size

The Uniform distribution, PERT distribution and triangular distribution are primarily used for defining expert opinion. The most crude of these is the Uniform distribution, which is used when little is known about the factor under consideration. The Uniform distribution is defined by the minimum and maximum, with an equal probability of a value being selected from any part of the distribution. The Triangular distribution is a commonly used distribution for modelling expert opinion as it uses minimum, most likely, and maximum values to define the factor of interest. As with the Uniform distribution the Triangular distribution selects values equally from any part of the distribution. The PERT distribution is similar to the triangular distribution, as it uses minimum, most likely, and maximum values to define the distribution of possible values. However, the PERT distribution does not evenly select values; rather it is four times more likely to select values from around the predetermined ‘most likely’ value. This means that a PERT distribution is less prone to bias from extreme minimum or maximum values, and it models natural variation better than the Triangular distribution.

R1, R2 and R3 – Selection of slaughter age pig infected with *T. spiralis*

The likelihood that a randomly selected pig is infected with *T. spiralis* depends on the probability of selecting an infected pig in an infected herd (within-herd prevalence)

and of selecting an infected herd from all herds eligible to export (between-herd prevalence). The type of herd a pig is sourced from affects its risk of carrying infection. Herd type was defined depending on the management system of the grower herd within the piggery. Commercial herds were split into non-confined (R1) and confined (R2). The third herd type was non-commercial (R3) piggeries producing small numbers of pigs generally for their own consumption and not registered with the New Zealand Pork Industry Board (NZPIB). These are generally unregulated backyard producers.

Confined herds are commercial piggeries that control the movement and activities of their pigs. Non-confined herds whilst still commercial do not restrain or control the movements of their pigs. Herds with a non-confined production system have a higher risk of infection than confined herds because of their higher risk of exposure to wildlife.

R1.1, R2.1, R3.1 are the between-herd prevalence estimates for non-confined, confined and non-commercial herds respectively. They estimate the likelihood for each herd type that *T. spiralis* is present in at least one grower pig in a randomly selected herd which is eligible for export.

R1.2, R2.2, R3.2 are the within-herd prevalence estimates for non-confined, confined and non-commercial herds respectively. They estimate the likelihood for each herd type that viable *T. spiralis* larvae are present at a burden of 1 larva/g or greater in a randomly selected pig from a herd that carries pigs infected with *T. spiralis* and is eligible for export.

Each pair of sub-variables (e.g. R1.1 and R1.2) are multiplied together to find the likelihood of the hazard occurring for each herd type as calculated below:

$$R1 = R1.1 \times R1.2$$

R4 - Proportion of production from each herd type

The proportion of pork produced by each production system differs, affecting the chance of selecting a pig from any one production system. R4.1, 4.2 and R4.3 define the percentage of pork products from each production system that may be exported from non-confined, confined and non-commercial herds respectively. Proportion of national production output was used to weight (R4.1, 4.2 and R4.3) the likelihood of selecting an infected pig in each production system (R1, R2 and R3) using the following equation:

$$R4 = (R4.1 \times R1) + (R4.2 \times R2) + (R4.3 \times R3)$$

R5 – Pig infected with *T. spiralis* is not detected by post-mortem testing

The likelihood that a viable larval burden of ≥ 1 larva/g of *T. spiralis* is not identified by the post mortem inspection depends on the sensitivity of the testing procedure as shown in the following equation:

$$R5 = 1 - \text{sensitivity}$$

Test sensitivity is a measure of how accurately the test detects disease (Streiner, 1998). A test with a sensitivity of 90% means that for 90% of positive samples the test will correctly identify disease status. The sensitivity of the post-mortem test depends on what type of test is used.

R6 - Larval burden in tissues for consumption

The likelihood that the tissues for consumption will contain a larval burden of ≥ 1 larva/g of viable *T. spiralis* larvae is dependent on the type of tissues that the pork product is derived from. Both offal (organs not containing skeletal muscle tissue) and cuts of skeletal muscle (pork) are desirable to importing countries. As larvae of *T. spiralis* only mature in the skeletal muscles, the LE estimate was calculated separately for offal and for skeletal muscle.

R7 – *T. spiralis* is not destroyed by post-mortem drop in pH

Muscle pH decreases over a 24 hour period after death from approximately 6.75 to an ultimate pH of 5.3-5.7 in normal muscle (Cassens, 1966). Death of the host alters the muscle environment that the parasite inhabits, as anaerobic glycolysis converts glycogen into lactic acid (Feidt and Brun-Bellut, 1999).

R8 - Survival of packing storage and transport

The likelihood that *T. spiralis* survives packing, storage and transportation depends on the conditions associated with each of these. Research has shown *T. spiralis* has a low tolerance to freezing (Kapel, 2000; Pozio et al., 1992) as larvae are killed by freezing at -15°C for at least 21 days (Bessonv et al., 2003).

5.2.1.2 Stage 2: Exposure assessment

The second part of estimating the risk of exposure to an individual is illustrated in Figure 5.2. Initially this assessment involved calculating the likelihood of entry and exposure (LEE). This was done by estimating the risk at each step of the assessment from the product entering the importing country to being ready for consumption. Lastly, the annual likelihood of exposure to *T. spiralis* for a consumer was calculated.

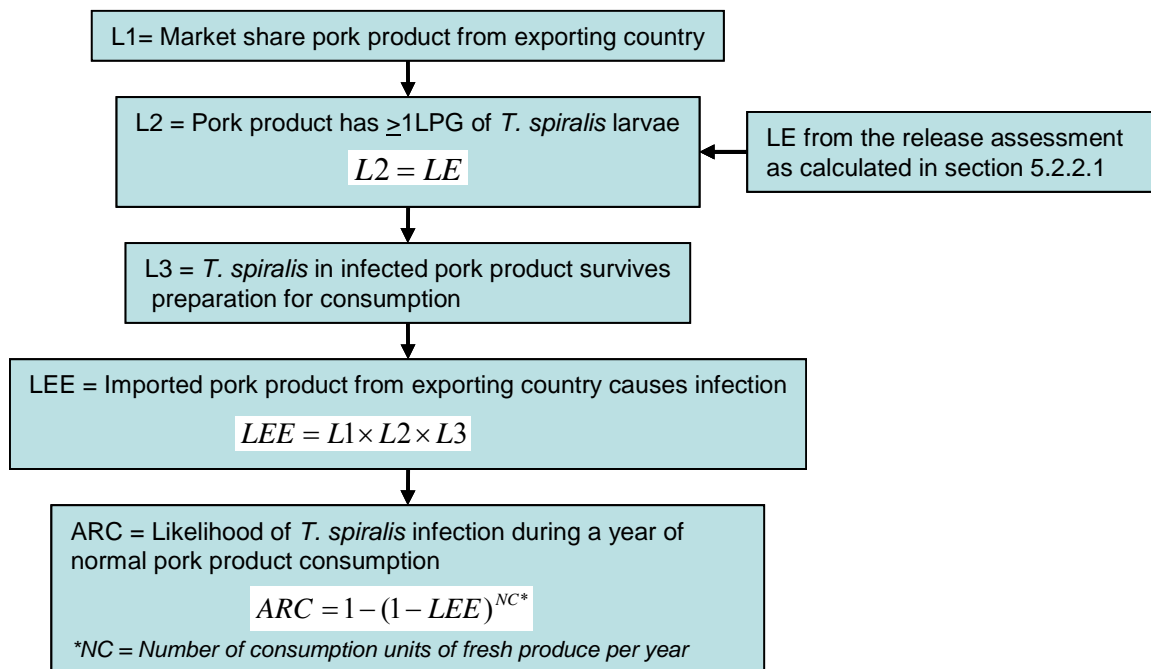


Figure 5.2 Steps in the exposure assessment for calculating the likelihood of entry and exposure for an infected pork product.

L1 – Chilled pork product originated from New Zealand

A pork product for sale in Singapore may have originated from several different countries. The likelihood that the product chosen for consumption came from New Zealand is directly related to the amount of New Zealand pork in the market, or the proportion of market share New Zealand holds in the Singaporean pork market. This proportion was entered into the exposure assessment as a single value from the calculation below:

$$L1 = \frac{\text{Volume from source country}}{\text{Total volume consumed by importing country}}$$

L2 – Pork product had a larval burden of ≥ 1 larva/g of *T. spiralis* capable of causing infection

This is the LE value that was calculated by the release assessment (see section 5.2.2.1).

L3 - *T. spiralis* surviving preparation for consumption

There are a variety of techniques to prepare pork products for consumption. Most of these involve cooking. How thoroughly the food is cooked will affect whether larvae are killed during preparation. Temperatures over 71°C will kill *T. spiralis* larvae (Gajadhar and Gamble, 2000). However, cooking does not raise temperatures to this level uniformly throughout the product. This may result in a poorly cooked interior with live viable larvae.

ARC - Annual risk to a consumer

The annual risk to a consumer (ARC) was based on the assumption that a person has multiple chances of exposure to *T. spiralis* over time. Each meal is considered as a chance for exposure. Although the annual consumption per person of pork in Singapore is 25-28 kg from all sources, the actual amount of fresh pork eaten per serving will vary from person to person (Kiang, 1998; New Zealand Pork Industry Board, 2004). The exposure for a person was calculated as the number of servings per year and how many of these servings were fresh pork rather than frozen. This calculation is shown below:

$$\text{Annual risk to a consumer (ARC)} = 1 - (1 - LEE)^{NC*}$$

*NC = Number of consumption units of fresh produce per year.

5.2.2 Generation of model outputs using Excel

The model was constructed in Microsoft Excel (Microsoft Office Excel, 2003) using a set of interlinked worksheets. For a description of these work sheets, please refer to Appendix 5.4. The quantitative risk estimates were calculated from the Excel model using @RISK 4.5 for Excel (Palisade, 2005) with single Latin hypercube sampling. The model was designed to allow the model parameters and input information to be altered to analyse either a range of situations for New Zealand exports, or the risk to Singaporean consumers from importing other nation's pork and pork products.

The add-in tool @RISK 4.5 for Excel (Palisade Corporation, 2005) is used facilitate the inclusion of distributions into an Excel spreadsheet. Excel is designed to draw on single values in its calculations, but single values do not allow for variation in the data. @RISK allows Excel to draw on distributions of values for its calculations as well. Therefore, some of the input data for the model are distributions or a range to allow for natural variation, so each time the @RISK runs it may re-draw a slightly different input value from each of the distributions. Resultantly, in order to get an accurate representation of the model output, the model must be run multiple times. The process of the model running once is called an iteration. The model was set to re-run the calculations 1,000 times and so produce 1,000 iterations (see Figure 5.3). These 1,000 iterations are each slightly different data values which create an output distribution or risk curve. The output distribution can be graphed where the values on the x-axis of the distribution are the range of probability values and the y-axis displays the frequency that each probability value occurs. The outcome values for comparison have been drawn from this distribution of risk analysis values. The 50th, 75th and 95th percentiles were selected to represent the outcome of the risk distribution.

5.2.3 Defining the model inputs

The model was used to analyse both the restricted and unrestricted estimates for sourcing pigs for export. The unrestricted risk estimate involves all herds and assumes no controls on exports are in place. This unrestricted risk estimate demonstrates the hazard of *T. spiralis* infection in any domestically produced pig in New Zealand and it provides the base values from which the effects of the restricted estimates are calculated. The restricted estimate uses the same model as the unrestricted risk, but selected inputs are removed or altered to simulate the different management situations. The restricted risk estimate is the risk that remains once further controls to prevent exporting a pig with *T. spiralis* have been implemented. The input values stated in sections 5.2.3.2 and 5.2.3.3 are reported in Appendix 5.1.

5.2.3.1 Risk assessment: Unrestricted estimate

The following two sections describe the release and exposure assessment of the model with parameters from the unrestricted estimate.

5.2.3.2 Input values for release estimate

R1 and R2 - Selecting a pig from a commercial herd

The sub-variables R1.1 and R2.1 model the number of commercial herds in New Zealand that may carry infected pigs. The outcome of Government testing from 1983 to 2004 on commercial herds provided 95% confidence of detecting *T. spiralis* at a prevalence of 0.5% (Clear and Morris, 2004). This testing provided the maximum prevalence value for the between-herd prevalence of commercial herds.

A PERT distribution was used to model the sub-variables R1.1 and R2.1. The negative government testing provided the minimum and most likely values, which were entered as a zero value. As the test is sensitive to detecting disease down to 0.5% we have used a maximum value of 0.005 for confined commercial herds which allows for potential sampling error. Compared to confined herds, non-confined commercial herds had a higher chance of exposure to wildlife and so a higher maximum value of 0.025 was entered.

The sub-variables R1.2 and R2.2 are the within-herd prevalence of *T. spiralis* for a randomly selected pig from an infected commercial herd. As no positives have been found in a New Zealand commercial herd the input values for these sub-variables were based on a study of commercially raised pigs from the north eastern United States of America (Gamble et al., 1999). The within-herd prevalence of the 156 sampled herds was up to 10%. From this, the input value of 0.1 was entered as a point estimate for the within-herd prevalence for confined commercial herds (R2.2). However, non-confined herds have unrestricted access to rodents and wildlife that can aid the transmission of the parasite (Gamble and Bush, 1999) and therefore 0.4 was entered as a point estimate for the within-herd prevalence for non-confined commercial herds (R1.2).

R3 - Selecting a pig from a non-commercial herd

In developed countries *Trichinella* infection is usually associated with small farm pig rearing for personal, or local consumption (Joshi et al., 2005; Kapel, 2005; Pozio, 2000). In New Zealand, two investigations have been carried out on infected herds. The first was in 1997 in Rotorua when the discovery of *T. spiralis* in a pig carcass initiated an investigation. The whole herd of 31 pigs on the property were slaughtered and tested using the pepsin digest method. However, the prevalence of infection was only assessed for the adult population. This prevalence was 44% (Paterson et al., 1997).

The second herd investigation was carried out in Whangamata in 2001 where 31 adult pigs were tested from the farm and 16 pigs tested positive (Thornton and King, 2004).

This second investigation was used as the input values for a Beta distribution to allow for uncertainty around these values. This uncertainty is because only one herd is considered for this estimate, so a distribution must be used to allow for variations in New Zealand non-commercial herds.

The between herd prevalence for the backyard production systems was modeled as a pert distribution where the input parameters were a minimum of zero, most likely value of 0.002 and a maximum of 0.05. These numbers were based on a number of assumptions. Firstly, the minimum was assumed to be zero because despite large numbers of backyard producers, many of whom kill and cure their own pork and bacon, there have only ever been four human cases in New Zealand. The most likely value was set at 0.002, based on the assumption that the prevalence in these systems is low but likely to be higher than that in commercial farms. The maximum was entered into the model as 0.05 as this was considered the worst case scenario.

R4 - Proportion of production

The more intensive confined commercial herds have a higher level of production as the pigs are housed indoors so their environment can be controlled to provide the ideal conditions for optimum growth. Expert opinion was consulted to estimate the contribution of each herd type to national domestic production (Morris pers comm., 2005). Pork from confined herds (R4.2) was considered to contribute to 98% of domestic production and non-confined herds (R4.1) 1% of domestic production. Although there are a very large number of non-commercial herds compared to commercial herds, the number of individual pigs on non-commercial farms (R4.3) is far fewer resulting in a relatively small contribution of 1% to the overall domestic pork production in New Zealand.

Input values for R5

There are two commonly used methods of carcass testing; trichinostomy and pepsin digest. The first method used was trichinostomy which involves microscopic examination of a 1 g sample of meat between two plates of glass. The second method is the pepsin digest test where the muscle tissue is digested using pepsin enzymes to

release the *Trichinella* larvae which are then examined microscopically. The pepsin digest test is recommended by the OIE because it has a higher sensitivity than the trichinoscopy method.

The sensitivity of the test was zero for the unrestricted estimate because there was no post mortem test and visual inspection would not detect contaminated carcasses.

Input values for R6

Trichinellosis is often more of a problem when poor food hygiene allows cross-contamination to occur. Cross-contamination at the butchering stage, or incomplete removal of adjoining skeletal muscle could lead to *T. spiralis* being found in tissues other than skeletal muscle, for example, offal. However, New Zealand abattoirs have very high meat hygiene standards and strict regulations (Animal Products Act, 1999). These include the requirement that all blades and other butchering equipment are washed between pigs to avoid cross-contamination between carcasses. As a result of these practises the probability of cross-contamination between carcasses is negligible.

The input values for R6 depended on whether the product was pork or offal. Offal has an extremely low risk for being contaminated with ≥ 1 larva/g of *T. spiralis*. This low risk was modelled using a PERT distribution with a minimum and most likely value of zero, and a maximum value of 0.005.

The input values for pork were entered as a PERT distribution, where the most likely value was taken from a case in 1997 where three of four infected pigs (75%) had larval burdens of ≥ 1 larva/g (Paterson et al., 1997). For the pert distribution the minimum value was 0.65, the most likely 0.75, and the maximum value was 0.85.

Input values for R7

Trichinella is tolerant of post-mortem pH changes and is readily passed on to animals scavenging off the carcass of a dead host several days after death (Nockler et al., 2000; Wakelin and Goyal, 1996).

Therefore a point estimate of 0.99 has been given to R7 because it is highly unlikely that post-mortem changes will affect the survival of *T. spiralis* in porcine tissues.

Input values for R8

This temperature is consistent with normal freezing of meat and the time of 21 days would be usual for frozen pork to be distributed to point of sale, especially if that was offshore. The risk of viable *T. spiralis* being present in frozen pork is negligible. Fresh pork for export would be chilled. Chilling is between -1°C – 8°C which does not sufficiently reduce temperature to affect viability of larvae (Gamble, 1999; Smith, 1975).

Therefore a single probability value of 0.99 was given to the likelihood that *T. spiralis* would remain viable at the end of the R8 step if it was present at the beginning because chilling, packaging and transportation of pork is unlikely to affect *T. spiralis* infectivity in pork.

5.2.3.3 Input values for entry and release estimate

Input values for L1

New Zealand's market share of freshly chilled product was estimated by the New Zealand Pork Industry Board to be 5% of Singapore's total market volume (New Zealand Pork Industry Board, 2003). Singapore's total market volume of freshly chilled product was taken from the World Trade Atlas for Singapore's total imports for selected pig products from November 2003 to October 2004 (Singapore Customs, 2004). The values used were 1,381 tonnes of offal and 5,557 tonnes of pork.

Input values for L2

The unrestricted input value was the unrestricted likelihood of entry estimate, as calculated in section 5.2.3.2.

Input values for L3

Different cooking practises are used for the different products which alters the likelihood of *T. spiralis* larvae remaining viable after preparation for consumption. As pork was considered to be more thoroughly cooked than offal, offal was allocated a ten times higher risk of carrying viable *T. spiralis* larva than pork. The point estimates were derived from expert opinion. This was reflected by allocating a point estimate of 0.01 to pork and 0.1 to offal.

5.2.4 Risk assessment: Restricted estimates

Five different risk management strategies were examined. The risk management strategies were exclusion of the high risk herd types from export, certifying production and management practices used by piggeries and using pepsin digest testing. These strategies are outlined in Table 5.1.

Table 5.1 Risk management strategies to mitigate the residual risk of *T. spiralis* in pork.

Risk Management Strategy	Herd Type Eligible for Export			Industry Action	
	Non-commercial	Non-confined	Confined	Certification	Testing
1 – Excluding non-commercial	no	yes	yes	no	no
2 - Confined only	no	no	yes	no	no
3 - Certified confined	no	no	yes (selected)	yes	no
4 - Certified non-confined	no	yes (selected)	no	yes	no
5 - Pepsin testing	yes	yes	yes	no	yes

The risk estimates for each management strategy were calculated by altering the values used for assessing the unrestricted risk estimate.

Management strategies 1 and 2 – Excluding high risk production systems:

These strategies involved excluding non-commercial and non-confined herds from production. The strategies did not affect the prevalence of *T. spiralis* in the production system; rather they removed the most at-risk production types from the model.

Exclusion of non-commercial pig farms

This management strategy was modelled by setting R4.3 to zero. Due to the removal of products from non-commercial herds, the production weighting for non-confined herds increased, which changed R4.1 to 2%.

Exclusion of non-commercial and commercial non-confinement production systems

This management strategy removed R1, R3, R4.1 and R4.3 from potential selection for export. Due to the removal of products from non-commercial and non-confined herds, production for export only came from confined herds, which increased R4.2 to 100%.

R6 remained the same in this model for offal, as it was already negligible. However, the likelihood, estimated using the PERT distribution, that infected pork carried a burden of ≥ 1 larva/g (R6) is lowered by the removal of non-commercial and non-confined herds. This is due to the lowered transmission risk of *T. spiralis* in confined commercial herds. In the assessment this was modelled by changing R6 to have a minimum value of 0, a most likely value of 0.01, and a maximum value of 0.05.

Management strategies 3 and 4 - Certification:

The broad classification of commercial herds into confined or non-confined allows for a wide range of management and biosecurity standards. Good biosecurity measures include high levels of on-farm sanitation which reduce the chance of *T. spiralis* transmission in piggeries (Stojcevic et al., 2004; van Knapen, 2000). The certification process selects herds that have an effective rodent control programme; maintain buildings clear of rubbish, debris and long grass; purchase pigs and feed from an approved source; and rapidly dispose of pig and wildlife carcasses. Under certification, farms would undergo annual audits by a registered individual who is independent of the pig producer and exporting companies to ensure standards are maintained. These measures are all considered to reduce the risk of the transmission of *T. spiralis* to pigs.

Certification of a farm does not affect the within-herd prevalence; rather it would reduce the likelihood of selecting a commercial herd with *T. spiralis* as only well-managed herds are certified for export. It also reduced the variation in herds for export.

Certified non-confined commercial production system

This management strategy was designed to assess a risk management possibility for only non-confined commercial herds. The strategy was modelled by setting R4.2 and R4.3 to zero, which effectively removed confined and non-commercial herds from selection. The effect of certification was modelled by reducing the between-herd

prevalence estimate for certified non-confined herds (R1.1) by 30%. It was expected that when products from non-confined herds were exported, products from confined herds would also be exported. Therefore, the amount of product from non-confined commercial (R4.1) was maintained at 1%.

Certified confined commercial production system

This management strategy was modelled by setting R4.1 and R4.3 to zero. The effect of certification was modelled by reducing the between-herd prevalence estimate for certified non-confined herds (R2.1) by 70%. Due to the removal of products from non-commercial and non-confined herds, production for export came only from confined herds, which increased R4.2 to 100%.

Management strategy 5 - Pepsin testing:

A further strategy is to manage risk at the post-mortem stage. Current legislation on exporting pork is that all carcasses for slaughter must be individually examined using pepsin digest. Accordingly, this control method was included as a risk strategy in order to compare current practises against other proposed methods.

The values for this model remained the same as for the unrestricted estimate, with one exception. The post mortem test sensitivity (R5.1) was changed from zero to a uniform distribution with a minimum of 0.95 and a maximum of 0.98 (Australian Government - Department of Agriculture Fisheries and Forestry, 2004; Bessonv et al., 2003).

5.2.5 Interpretation of model output values

The output of the model was assessed to consider the annual risk to a consumer, and whether the risk estimate at the 95th percentile was less than one in a million. Percentiles represent the risk estimate at a certain part of the curve. The term percentile refers to percentages, where each percentile represents a probability value below which the nominated percentage of values lies. For example the 50th percentile refers to the part of the curve where 50% of the risk estimate values in the model distribution are lower than that value given as the 50th percentile. We were most interested in the higher risk values because they acknowledge any residual risk present. The 95th percentile was

used to represent these upper limits of the risk estimates to compare the final results of each risk management model.

A risk estimate of less than one in a million (1×10^{-6}) was considered to be a negligible risk by the Australian Government's Department of Agriculture, Fisheries and Forestry in their guidelines for import risk analysis (2004). The 95th percentile was considered an extremely strict requirement, and was used to ensure that there was a wide margin of safety by considering almost all of the potential risk estimates from the model.

5.2.6 Sensitivity Analysis

A sensitivity analysis was carried out on the model outputs in @RISK 4.5 (Palisade Corporation, 2005) to identify how strongly each input variable influenced the model outcome. The sensitivity analysis used the Spearman rank correlation coefficient calculations as this method does not make assumptions about the relationship between variables (Anon., 2004b). The Spearman rank correlation calculated the correlation between the output variable, annual likelihood of exposure, and the input distributions. These correlations were then ranked to assess which input variables were most significant in determining the values of the model output (Anon., 2004a). Input variables that had a significant effect on the model outcome were analysed further to assess the magnitude of the effect on the risk to a consumer.

5.3 Results

5.3.1 Comparison between offal and pork for the unrestricted risk estimate

The risk estimates for pork and offal both gave a similar output distribution (Figure 5.3) although the results were on a very different scale. Risk estimates for offal were 100 times smaller than those for pork. The results for the annual probability of exposure of infected offal to a consumer from unrestricted sources at the 95th percentile, was 1.7×10^{-7} . As this was less than one in a million the unrestricted risk from offal was considered to always be safe. In comparison the unrestricted risk value at the 95th percentile for pork was 1.8×10^{-5} . Although very low this value was higher than the preset safety threshold of 1 in a million (1×10^{-6}).

Consequently, risk management strategies were considered with respect to reducing the risk from pork products to below the predetermined safety threshold of one in a million.

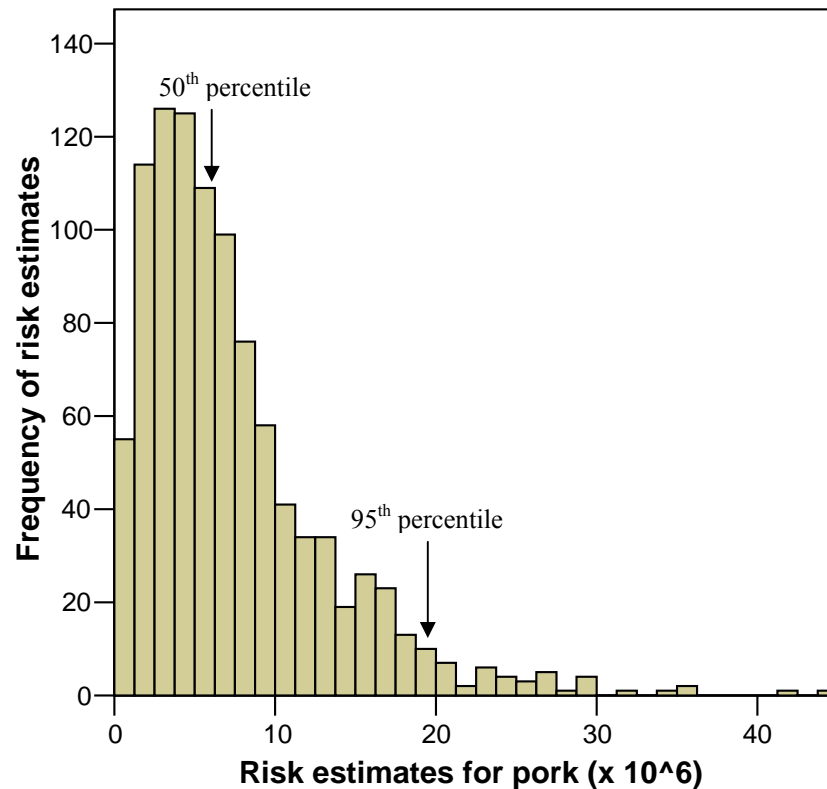


Figure 5.3 The distribution of 1000 iterations from the model for the unrestricted risk estimate for pork. The position of the 50th and 95th percentiles are shown.

5.3.2 Comparison of unrestricted and restricted risk strategies for fresh pork

Of the five management strategies assessed to control the risk of *T. spiralis* in unrestricted sources of fresh pork, three effectively reduced the risk to below the threshold of 1×10^{-6} . This is outlined in Figure 5.4 where only confined herds, either certified or not certified, and using the pepsin digest post-mortem test, gave an effective reduction of risk.

Figure 5.4 also outlines the variation in model outputs. This figure shows that there is far greater variation in the risk estimates from the unrestricted model and from excluding non-commercial model than the other scenarios. This suggests that the non-commercial group increase the variation in the risk assessment outputs. This is further

shown in Appendix 5.3 where the inter-quartile range and the range describe the spread and the trends in the data.

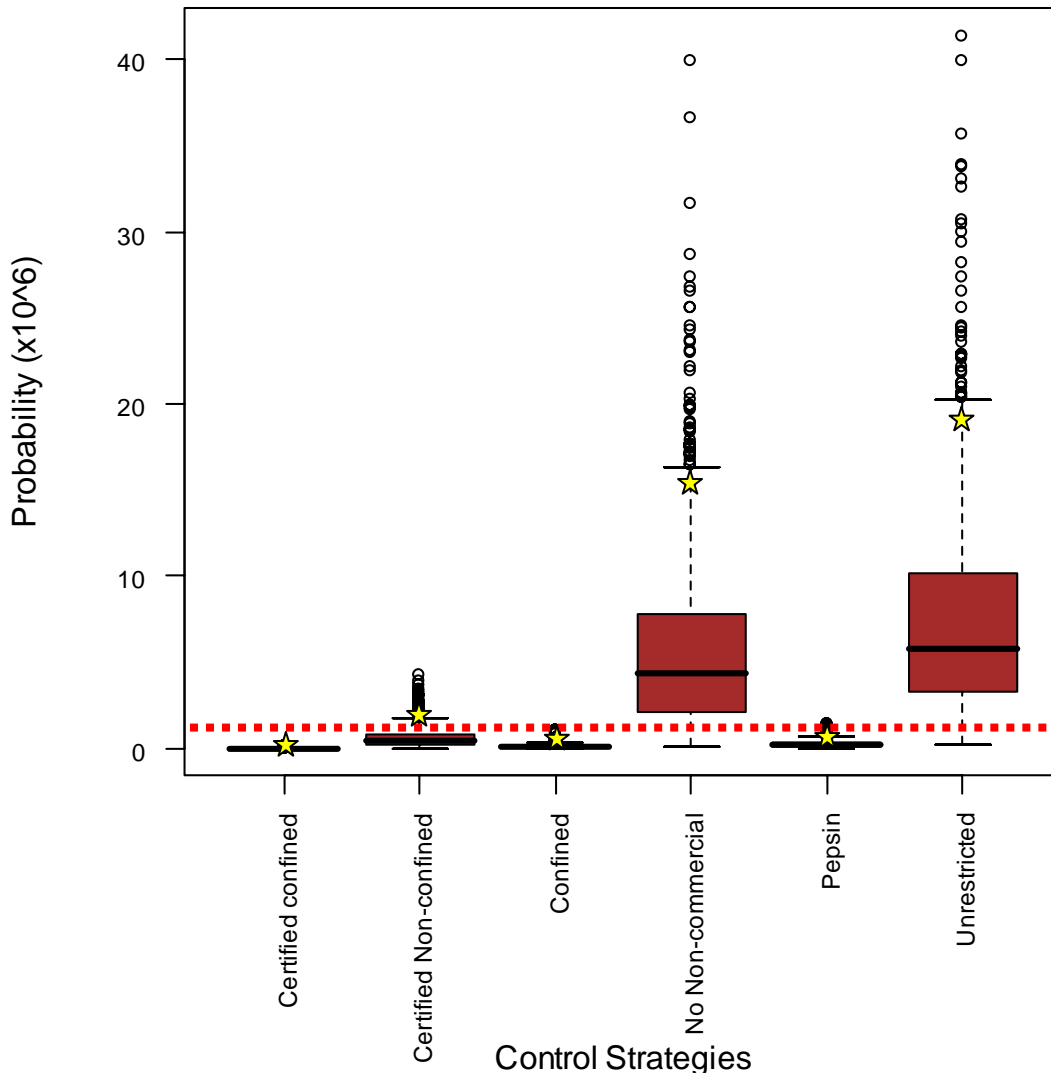


Figure 5.4 Box and whisker plots of the model outputs for the six different control strategies for *T. spiralis* in New Zealand pork products, illustrating the variation in the distribution of the outputs from each model, and comparing all models to the threshold value of one in a million. The 95th percentile is shown by a star.

5.3.3 Sensitivity analysis results

A sensitivity analysis was carried out on models for pork, but not for offal, as the numbers in the offal model were too small to calculate sensitivity values. The sensitivity results for this strategy have been presented for the certified confined management strategy as it had the lowest risk value, making it the most suitable for controlling *T. spiralis* in exported products. The largest sensitivity values indicate

which of the model inputs most strongly influence the outcome of the model. The four largest sensitivity values for the annual probability of exposure of an infected product to a consumer for the unrestricted model and the certified confined model are presented in Table 5.2.

Table 5.2 The sensitivity analysis for input variables of the annual probability of exposure to *T. spiralis* to a consumer, in New Zealand pork.

Unrestricted risk estimate	Correlation co-efficient
Between herd prevalence for confined production	0.596
Amount of fresh pork in the diet per year	0.544
Size of consumption unit	-0.349
Between herd prevalence for non-commercial production	0.380
Certified confined commercial herds	
Between herd prevalence for confined production	0.524
Level of infection in confined and certified pigs	0.504
Amount of fresh pork in the diet per year	0.234
Size of consumption unit	-0.160

As the amount of fresh pork in the diet per year and the size of the consumption unit could not be controlled by the producer, some further analysis was required to assess the effect that changes in these factors would have on the risk estimate for the consumer. Fresh pork was modelled at 100% of pork intake in the diet, rather than 55%. This only increased the risk by 9×10^{-9} which maintained the risk at well below one in a million. Doubling the size of the consumption unit and increasing the average annual intake of pork by 5kg also had no effect on the safety of pork products.

5.4 Discussion

A generic model has been developed to define the risk of a food-borne pathogen in exported pork. This model has been tested on the parasite *T. spiralis* entering Singapore from New Zealand. The model provides a user friendly interface to compare the food safety risk for different export strategies. Quantitative risk assessment techniques determined that the risk of *T. spiralis* in New Zealand exported pork products is very low. The risk of contracting trichinellosis from the consumption of offal that does not contain skeletal muscle was found to be negligible at all times. However, the unrestricted annual risk to a consumer for pork products was over one in a million at the 95th percentile. This risk could be reduced to less than one in a million by introducing

one of three strategies. These were either selecting the herds that were allowed to export on their herd management practises, preferably through a certification program, or by pepsin digest testing every pig from which any product may be exported.

Currently pepsin digest testing is used to identify infection in pork. The pepsin digest test is designed to detect infection at a level likely to cause disease in humans. However, this test does not directly impact on reducing disease in pigs, and human error and accidents will always allow for some probability of infection from tested meat (Gajadhar and Forbes, 2002; van Knapen, 2000). Factors that affect the quality and reliability of the pepsin digest are having an experienced laboratory technician, the sieve size used, having adequate sample sizes of tissues for testing, and potential variations to the standard technique (Bessonv et al., 2003; Gamble, 1999).

Good on-farm management has been shown to effectively control *T. spiralis* in infected herds (Bessonv et al., 2003; Dupouy-Camet, 2000). In particular, preventing wildlife and rats from coming into contact with pigs or pig feed appear to be paramount in maintaining a *Trichinella*-free pig herd (Gamble and Bush, 1999; Murrell et al., 1987). Rodents and wildlife are a concern for transmitting infection between pigs (Enemark et al., 2000; Leiby et al., 1990). The certification program addresses the control of wildlife through several steps. Firstly active rodent populations, particularly populations of *Rattus norvegicus* (the Norway rat) must be eradicated and carcasses disposed of in a manner that does not allow pigs or other animals to come into contact with them. Also the farm environment must be such that it discourages habitation by wildlife. Long grass, vegetation and rubbish all provide shelter and food sources for wildlife, which aids their persistence in and around the piggery and so must be removed (Corrigan, 2001; van Knapen, 2000). Another potential source of exposure of domestic pigs to *T. spiralis* is through food scraps in garbage (Gamble et al., 1999). Certification allows for the removal of herds from export that feed their pigs non-grain diets. The primary route of transmission for *T. spiralis* is from infected carcasses, and as a result the rapid removal of carcasses from the piggery ensures this type of transmission does not occur (Kapel, 2000). To maintain the credibility and standards of the certification program certified farms are required to be assessed by an independent party that does not have a vested interest in the farms being certified.

Restricting the source of exported pig products to only confined herds was the most cost effective way to reduce the risk from trichinellosis. This acknowledges that the main source of infection for farmed pork is from pigs and pig feed coming into contact with infected wildlife, especially rats, but also cats and possibly mustelids or even possums (Gamble et al., 1999). Modern, confined commercial piggeries generally include a measure of rodent control and factors that reduce the risk of contact with wildlife (Kociejka et al., 2003). Another common factor of confined pigs is that they can only consume the diets prepared for them, which reduces their exposure to unsatisfactory food sources. A potential limitation with using ‘confined’ as a category, is that it includes a wide variety of management types and efficiencies of production. Nevertheless, selecting only confined herds was still identified as the most substantial contribution to reducing the risk of trichinellosis in exported pig products.

The lowest risk strategy was to only export pork meat from certified confined herds. This option resulted in the lowest risk to the consumer, and allowed exporting bodies to control the quality of their product. Certification of pig herds for controlling *T. spiralis* is a novel approach to the long-standing problem of reducing the risk of trichinellosis from pig products. Approaches to certification have been proposed in the United States of America (Davies et al., 1998; United States Department of Agriculture, 2003), and Europe (Nockler et al., 2000; van Knapen, 2000). However, these approaches propose that additional measures, such as routine serology testing, are necessary. With our quantitative model, certification alone was shown to provide very good risk management. Certification provides a benchmark for management practices aimed to stop the transmission of *T. spiralis* in commercial piggeries.

Sensitivity analysis can be used to identify the most important factors in the production chain that may be a risk for *T. spiralis* infecting New Zealand pork. This means that the model not only estimates the risk, but is also a useful tool to predict which parts of the chain need closer monitoring, or further attention. The sensitivity analysis conducted here identified that the between-herd prevalence for confined commercial herds was strongly correlated to the output of the model for the unrestricted estimate. The input value for between-herd prevalence for confined commercial herds was based on government testing, using the pepsin digest test, which provided a 95% confidence that prevalence in commercial herds was below 0.5% (Clear and Morris,

2004). Furthermore this test series was for all commercial farms, and it has been well documented that improved on-farm sanitation will decrease the risk of trichinellosis (Gamble et al., 1999; Pozio, 2001; Stojcevic et al., 2004; van Knapen, 2000). The aim of certification is to select farms with good sanitation practices; therefore it is reasonable to expect a reduced risk of *T. spiralis* transmission on these farms. Given the importance of this factor, the model outputs shown here are likely to overestimate the risk from confined certified herds.

The proportion of fresh pork in the diet was also found to be a significant factor in driving the outcome of the model. This factor is of interest as the proportion of fresh pork in the diet could vary substantially for an individual, which raises the concern of whether high proportions of fresh pork in the diet would put a consumer of New Zealand pork at significant risk. However, when the effect on the annual risk of trichinellosis for an individual was evaluated given a proportion of fresh pork in the diet at 100%, rather than the estimated 55% used in the model, the risk was still negligible, as the likelihood of infection was still very low at 1.9×10^{-8} . Therefore, although this factor is a significant input factor for the model, changes to this input value do not put the consumer at risk.

The sensitivity analysis for certified confined commercial herds identified that the level of infection in a product was an important factor. An assumption was if larvae were present in pork from certified farms, they would occur in lower numbers than for infected pork from the unrestricted situation. Studies support that a reduction in the transmission of *T. spiralis* in the piggery lowers the likely number of larvae per gram of muscle tissue (Gamble et al., 1999; Schad et al., 1987). This means that consuming an infective dose of *T. spiralis* is very unlikely from commercial pork, given that it is likely to have a very low larval burden if it were infected.

The size of the consumption unit also influences on the model output. As with the amount of fresh pork in the diet, this factor cannot be controlled by the pork producer. This factor is strongly correlated with the outcome such that if a portion is infected; the larger it is the more larvae it will carry. However, if a larger portion of pork is consumed the annual risk becomes lower per person due to the fewer chances of exposure the person has given overall consumption statistics (Kiang, 1998; New Zealand Pork Industry Board, 2004). The risk still does not exceed the acceptable

threshold when average portion size is doubled and the average annual consumption is increased by 5 kg. The reduction in risk from eating larger portion sizes is due to having a smaller number of consumption units, which means that there are fewer chances for exposure for a consumer.

A feature of modelling that often causes debate is the use of expert opinion as a data input. This is necessary as sometimes there is insufficient data to fill all the steps of the model. A weakness in the model was the poor availability of data in some areas such as the within-herd prevalence of *T. spiralis* in a commercial herd. In the model it was decided to model expert opinion on the reduction in larval viability by cooking (L3) as a point estimate. Alternatively this same value could have been modelled using a triangular distribution. These alternatives were not explored during this study.

Although the risk analysis follows the guidelines stated by the OIE it does not incorporate all the usual features of a risk analysis. As there is a pre-defined hazard (*Trichinella spiralis*) and as the model is centred on exportation, the bulk of the model is focused on the release assessment. This means that if this model was used to assess the risk of exporting infected meat to a country with its own domestic swine population, then a consequence assessment would need to be added to the current model.

In this study a quantitative risk assessment was successfully used to estimate *T. spiralis* infections in pigs for export. Improving international market access facilitates further development of local industries (Gajadhar et al., 1997). This model was taken to Singapore in May 2005, where it was approved by the Agri-Food and Veterinary Authority of Singapore, and it has since been included as part of the New Zealand export program for fresh chilled pork and offal to Singapore. The certification process will involve cost for those that wish to comply as well as national costs in setting up the program such as, requiring higher production, specialised processing and the production of heavier gilts for market, as well as additional staff (New Zealand Pork Industry Board, 2003). However, these costs would be offset by expanding market opportunities and a new source of revenue for the New Zealand pig industry. The outcomes of this model have been integrated by the New Zealand Pork Industry Board into their export strategy, and as a result they are now exporting fresh chilled pork products to Singapore.

6 General discussion

This thesis examines *Trichinella spiralis* in New Zealand using four different approaches. *T. spiralis* levels were surveyed in wildlife to ascertain the likely infection pressure to domestic pigs. In parallel to this, rodent control methods were investigated on commercial piggeries to examine if effective barriers could be set up between rodents and pigs, as it has been implied that rodents play a key role in spreading trichinellosis within piggeries (Cairns, 1966; Mason, 1978; Liberona and MacDiarmid, 1988). Piggery management practices in New Zealand were investigated on a national scale with particular relevance to *T. spiralis* transmission.

Computer simulation modelling is a cost-effective and time-efficient method of evaluating potential control options for *T. spiralis* and identifying important areas of uncertainty in the epidemiology of the disease. In this study, simulation modelling suggested a very low risk of contracting trichinellosis from New Zealand pork or pork products. Setting up the model highlighted several unstudied parameters about *T. spiralis* in New Zealand and globally. The within-herd prevalence of *T. spiralis* in an infected herd, and also the likely larval burden of an infected pig in an infected herd, were both points that appear poorly documented.

The national survey conducted here found rat activity in 85% of piggeries and cats living on 60% of piggeries. If *Trichinella* was truly wide-spread and 'endemic' and transmitted by cats and rats to pigs, then there should be more cases of trichinellosis, or positive findings. The rodent control study found that the likelihood of finding rats around grower pigs was two to four times higher than around other classes of pigs. If rodents were a real risk factor for transmitting *T. spiralis*, then higher prevalence rates should be found in grower pigs. This was so in a Slovakian study by Hurnikova (2005) who found a high rate of trichinellosis in grower pigs. Although the former tested more sows than grower pigs, the prevalence of infection was found at only 1% in sows and 6% in grower pigs. This suggests that testing should focus on grower pigs to maximise the chance of detecting *T. spiralis*. The food safety issue lies with grower pigs as they are the highest risk group and also the group that is raised for human consumption.

The cause of infection for the first two New Zealand human cases was not confirmed, with locally produced pork suspected to be the source (Cairns, 1966; Mason, 1978). As New Zealand import a large amount of pork for the domestic market there is the potential for infection to re-enter the country. The possibility of this occurring is outside the scope of this study, and depends on the surveillance methods used in the exporting country. In New Zealand, routine surveillance is carried out on older breeding pigs or “chopper pigs”. Previous to the pepsin digest testing programme, trichinostomy was used to survey pigs. From 1969 to 1983, 300,000 culled breeding pigs were tested by trichinostomy for *T. spiralis*; all were negative (Clear and Morris, 2004). All exported feral pigs for consumption have also been tested, and all were negative (Clear and Morris, 2004). The existing Pepsin digest method provides a 95% probability of detecting infection at 0.5%. This is the minimum sensitivity standard specified for *Trichinella* surveillance by the World Organisation of Animal Health (Anon., 2004).

The current testing method is not providing further information about potential reservoirs of *T. spiralis* in New Zealand. In 2004, a horse was identified under routine testing pre-export from New Zealand (New Zealand Veterinary Association, 2004). Horses have been the cause of 13 outbreaks of trichinellosis in Europe since 1976, and infections in this host have caused considerable concern as it is not clear how this host becomes infected (Boireau et al., 2000; Pozio et al., 2001). The detection of *T. spiralis* in a New Zealand horse is evidence that the parasite is being maintained in the New Zealand environment. In Ireland, no infection in humans or domestic animals had been documented for 34 years, however, on carrying out a survey using the artificial pepsin digest method in red foxes, *T. spiralis* was detected at a prevalence of 0.9% (Rafter et al., 2005). This study is an example of how *T. spiralis* can be maintained in the sylvatic environment for many years. Further work is necessary to identify the reservoir for *T. spiralis* in New Zealand (Pozio and Zarlenga, 2005).

A central issue that should be addressed is identification of the source of *T. spiralis* infections in New Zealand. New Zealand does not have a wide range of suitable hosts, unlike North and South America, and Europe. Switzerland, Finland, Denmark, Germany, Ireland, and Greenland all used foxes to ascertain the prevalence of *Trichinella* in wildlife (Kapel et al., 1996; Gottstein et al., 1997; Wacker et al., 1999;

Enemark et al., 2000; Oivanen et al., 2002; Rafter et al., 2005). Similarly, lynxes, badgers, bears and raccoon dogs appear good indicators for *T. spiralis* in wildlife (Pozio et al., 1996; Murrell and Pozio, 2000; Oivanen et al., 2002). These species are not present in New Zealand. Previous studies suggest that rats are the source of *T. spiralis* infections in pigs, and consequently people, in New Zealand (Cairns, 1966; Liberona and MacDiarmid, 1988; Clear and Morris, 2004).

The finding of *T. spiralis* in rats at the Feilding landfill in 1968 supports the theory that rat populations can be reservoirs for infection, as pigs were not present at the site where *T. spiralis* was found (Liberona and MacDiarmid, 1988). During the same national survey in 1968, infected rats were also identified at a Feilding piggery, illustrating a situation where transmission could have occurred between pigs and rats in New Zealand. Our wildlife survey found no evidence of infection in rats from either sylvatic, or synanthropic habitats. This finding concurred with several similar studies on *Trichinella* in rats conducted overseas that, collectively, suggested that rats are questionable indicator species for *T. spiralis* (Ayala Bello, 1995; Pozio et al., 1996; Ortega-Pierres et al., 2000; Takahashi et al., 2000). This is particularly so in sylvatic habitats, as Norway rats are rarely found in native bush and forestry in New Zealand (Innes, 1990; Moors, 1990). In these areas ship rats predominate, and this species has never been found infected with *T. spiralis* (Pozio, 2005).

Infected cats have readily been found during both localised and national surveys for *T. spiralis* in New Zealand (Thornton and King, 2004). The difficulty in collecting sufficient samples, and the large number of negatives found in our wildlife survey, suggests that this is not the best method to determine the whereabouts of *T. spiralis* in New Zealand wildlife. In Greece and Finland, serological surveys using enzyme-linked immunosorbent assay (ELISA) were carried out on 1,000 and 727 dogs, respectively (Frydas et al., 1995; Oivanen et al., 2005). This method tests for *Trichinella* antibodies in sera and is the only serological method recommended by the International Commission on Trichinellosis (Smith, 1987; Nockler et al., 2000). Both of these studies appeared effective in identifying infection in dogs. This leads to the possibility that serology testing on cats, as they are widely distributed carnivore, could be an effective indicator for surveying sylvatic areas for *T. spiralis* in New Zealand. An advantage of serology testing over pepsin digest testing is this serology testing can be carried out on

live animals, which would mean that domestic cats could potentially be tested also. The survey of cats conducted as part of this thesis was insufficient to draw conclusions about the prevalence of *T. spiralis* in cats. Potentially hunting dogs, such as pig dogs, may also play a role in maintaining *T. spiralis*, and should also be surveyed.

Serology could provide a useful surveillance tool for testing grower pigs in New Zealand (Davies et al., 1998; Nockler et al., 2000). Serology studies appear to add a significant level of sensitivity to a testing program (Gamble and Bush, 1999). Switzerland used serology testing as part of a successful campaign to verify that the country was *Trichinella*-free (Gottstein et al., 1997). Similar methods could be used in New Zealand to build on our model findings and conclusively establish the status of *T. spiralis* in domestic pigs.

While improvements could be made in the surveillance of both pigs and wildlife for *T. spiralis*, the current study indicates that the risk of humans contracting *T. spiralis* from eating pork or pork products from New Zealand commercial piggeries is exceedingly low. This result was used successfully in 2005 to support a case for relaxing the screening requirements for pig products exported from New Zealand to Singapore. The outcome of which is that exported products from certified herds do not have to undergo individual carcass testing. The model developed in Chapter 5 has the potential to be applied further through assessing other food borne pathogens that are a problem in pork and pork products.

Appendices

Appendix 2.1 – Standard operating procedures for Pepsin digest test

Equipment

Petri dish
600 mL beaker
Hot plate with a magnetic stirrer and flea
2L beaker
300 µm sieve
Thermometer
50 mL measuring cylinder

Reagents

Pepsin P7000 (1:10000 NF) from porcine stomach mucosa. Brand: Sigma.
Concentrated Hydrochloric Acid (HCL)

Step-by-step Process

1. Heat 1800mL of tap water to 47 °C.
 - a. Add 30mL concentrate HCl
 - b. Add 7.5g pepsin
 - c. Leave the pepsin to mix and dissolve.
2. From each rat sample, put the diaphragm, the tongue, and one cheek muscle (the smaller of the two) in a petri dish. Keep one cheek sample aside in case retesting is required such as the event of a positive result.
 - a. Finely chop the sample in the petri-dish using scissors or a scalpel into less than 5mm pieces.
 - b. Repeat this with the other samples in the batch. Batches should contain 10 (+/- 3) samples, or between 8-20g of sample.
 - c. Wash scissors and/or scalpel between samples and batches.
3. Fill 600mL beaker with 200mL of pepsin mix on a hot plate.
 - a. Add flea (stirrer)
 - b. Add whole sample batch to beaker and rinse petri-dish with pepsin mix (in squirt bottle from 2L beaker) into beaker.
 - c. Top beaker up to 400ml
 - d. Cover Beaker with tin foil.

- e. Check temp stays at 46 °C.
 - f. Leave for half and hour.
4. Once digest is complete the meat looks as if it has broken down, and the pepsin mix goes a brownish opaque colour because it contains digest.
5. Once the digest is complete, the batch is all poured through a 300 µm sieve into a funnel. Ensure funnel has a closed off tap at the bottom.
 - a. Rinse digest solids while still in sieve to wash *Trichinella* through sieve if they are there.
 - b. Remove sieve and dispose of sample solids in a safe manner. Rinse sieve thoroughly for use with the next batch.
 - c. Leave digest to settle in funnel for half an hour.
6. *Trichinella* will settle to the bottom of the funnel, so after the ½ hour settling period, the larvae should have collected at the bottom of the container.
 - a. Open bottom of funnel to collect 40mL of digest in a measuring cylinder.
 - b. Leave the digest to sit for 10 minutes.
 - c. Remove the top 30mL of digest. Replace with tap water and allow settling for another 10 minutes.
 - d. Repeat step 6c until the residual fraction is colourless and translucent.
7. Once the residual fraction is colourless and translucent.
 - a. Pour the remaining 10mL of sample into a petri-dish scored with a 5x5mm grid.
 - b. Allow sample to settle and examine the sample under a dissection microscope by following down the scored lines on the underside of the Petri dish.
 - c. The *Trichinella* larvae sit steady on the bottom of the dish and tend to be coiled up, with a translucent border.

Appendix 2.2 – Letter introducing the study to Farmers

Tuesday 24 June, 2003.

Their address

Dear *Name*

My name is Esther Richardson, and I am working towards a Masters degree in Veterinary Studies (MVS) at Massey University. My research focuses on rodent control and assessment of *Trichinella* in New Zealand piggeries.

The New Zealand Pork Industry Board is currently developing export opportunities for New Zealand pork, and in particular to Singapore. At present, every pig destined for these markets, must be tested for *Trichinella spiralis* - a procedure that adds time and cost.

To reduce delays and costs associated with testing, the NZPIB is developing a *Trichinella*-accreditation scheme to enable product from accredited farms to be exported without individual animal testing.

Rats are the main source of *Trichinella* infection for pigs, and my project will survey rodent populations throughout New Zealand to determine the level of infection in rats and the associated risk to pigs.

The study is based at the EpiCentre, under the supervision of Dr David Lawton, whom some of you may have heard speaking on this problem toward the end of last year. The study will determine rat *Trichinella* levels in commercial piggeries, DoC areas, and local rubbish dumps.

I am requesting your participation by providing dead rats for *Trichinella* testing. **This study will only be possible with your help.**

Confidentiality is assured, however your own farm results will be available on request to you.

Accompanying this letter is a brief outline of the study and what it involves.

Should you require any further information please do not hesitate to contact either myself or David Lawton.

Yours Sincerely,

Esther Richardson
Phone (wk): 06 350 4008
Cell: 021 033 1575
Email: E.Richardson@massey.ac.nz

Appendix 2.3 - Copy of a reply letter sent to a farmer

Their address

3 November 2003.

Dear *Name*,

Thank-you very much for your willingness to collect rats for the *Trichinella*-accreditation scheme. We really do appreciate your help. A greater range of farms that get involved will mean more rats that we can test, and this will give us more convincing and accurate test results. Providing conclusive research results on the status of *Trichinella* in New Zealand is a very important step towards gaining improved export opportunities for pork and pig products.

Included with this letter is an address label, courier ticket and box, which is for you to send the rats back to the EpiCentre. There is also a freezer pad (that will need refreezing!) to put in with the rats for the trip back to Massey to help slow down natural decomposition.

Once received, the rats they will be kept in the freezer for 2 weeks to kill any parasites that they may have before tissue samples are collected and tested. The tests for *Trichinella* have been tested and are ready. All rats tested so far have come up as negative. The results of the *Trichinella* study will be apart of a Masters thesis as well as be used to help NZ Pork open up over seas market opportunities.

We are aiming to test as many rats as possible so please keep in touch and keep sending in the rats that you catch. Should you require any further information please do not hesitate to contact either myself or David Lawton.

Yours Sincerely,

Esther Richardson
Phone (wk): 06 350 4008
Cell: 021 033 1575
Email: E.Richardson@massey.ac.nz

Appendix 3.1 – Cover letter and survey form for commercial piggeries management survey



Massey University

CONFIDENTIAL
ID _____

Trichinella-free Accreditation Program for New Zealand piggeries

Please return this questionnaire by the 30th of October

The New Zealand Pork Industry Board and Massey University are working to create an on-farm Trichinella-free accreditation program to replace current testing requirements for exporting pork products to overseas markets.

Why have we sent you this Questionnaire?

The aim of this survey is to gather knowledge that will empower the New Zealand pork industry to better manage the risks associated with rodent populations and their control on pig farms.

Your opinion and experience on this subject is invaluable, as we need your assistance in determining the current situation of rats and mice on pig farms throughout the country. We are therefore asking all commercial pig farms with over 100 sows (or sow equivalents) in New Zealand to participate.

Please answer all the questions. Approximate answers or your 'best guess-timate' are preferable to leaving answers blank. The survey data is absolutely confidential and anonymous. You are not asked for your name or any other personal details; however each form has a confidential ID number which is to facilitate data analysis. It is not to critique individual practices. The conclusions from the survey will be made available to farmers via the New Zealand Pork Industry Board.

Please take some time (it only takes 5-10 minutes to fill out) to complete the attached survey and to return it to me in the reply-paid envelope within the next three weeks. Thank-you for your support, I look forward to receiving your questionnaire!

If you have any queries or concerns about this survey, please feel free to contact me.

Contact: Esther Richardson, Epicentre, Private Bag 11222, IVABS, Massey University, Palmerston North. Telephone: (06) 350 4008 (Fax: (06) 350 5716)

Email: E.Richardson@massey.ac.nz

**MASSEY UNIVERSITY
INSTITUTE OF VETERINARY, ANIMAL AND BIOMEDICAL SCIENCE**

QUESTIONNAIRE FOR COMMERCIAL PIGGERIES

Pig Herd Characteristics

1. How is your pig herd structured?

Please give the number OR number and age range (in weeks) for the pigs you have in each of the categories below. If your farm doesn't carry a particular category, enter 'zero'.

	Number of Pigs		Number and age range(weeks)
Sows - including mated gilts	_____	Weaners	_____
Unmated gilts	_____	Growers	_____
		Finishers	_____

2. How are your pigs housed?

Please tick all housing types you use for each production category.

a) Dry Sows

Group housing in pens	<input type="checkbox"/>
Group housing in eco-shelters	<input type="checkbox"/>
Singularly in stalls	<input type="checkbox"/>
Outdoors	<input type="checkbox"/>
Other	<input type="checkbox"/>

b) Lactating Sows

Solari	<input type="checkbox"/>
Arc	<input type="checkbox"/>
Farrowing Crate	<input type="checkbox"/>
Other	<input type="checkbox"/>

c) Grower herd

	Weaners	Growers	Finishers
Conventional sheds	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Low cost shelter (eco-barn)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cosy kennels	<input type="checkbox"/>		
Weaner boxes	<input type="checkbox"/>		

3. How old are the buildings on your piggery that house pigs?

Please state an age range for your buildings; for example, if your oldest building is 50, and your youngest is 10, the range is 10 – 50 years. This only needs to be an approximate figure.

Pig Feed

4. Do you mill and/or mix your own feed?

Yes
No

5. What feed ingredients are used on your farm?

Please tick which ingredients you use, and if you tick grain or 'other' specify whether they are sourced on farm or off farm.

	Ingredient Used	Feed Sourced	
		On farm	Off farm
Compound feed	<input type="checkbox"/>		
Grain	<input type="checkbox"/>	Grain <input type="checkbox"/>	<input type="checkbox"/>
Meat & bone meal	<input type="checkbox"/>		
Blood meal	<input type="checkbox"/>		
Soy	<input type="checkbox"/>		
Fish Meal	<input type="checkbox"/>		
Other feed used on your farm	<input type="checkbox"/>	Other <input type="checkbox"/>	<input type="checkbox"/>

Type of 'other' feed used:

6. What type of by-products do you feed?

Please tick all that apply

Bread
Other Bakery by-products
Domestic food waste
Un-rendered meat products
Dairy by-products (e.g. cheese and whey)
Other
None

7. What type of feeding method do you use?

Wet
Dry
Mix of both methods

8. How do you store your feedstuffs?

Please tick which feed storage type applies to your farm, for each of the three categories.

	Unmilled Grain	Ingredients for mixed feed	Mixed feed
In bags on wooden pallets	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In bags - loose stacked	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In silos	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Open topped Bins	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Not applicable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Farm Environment

9. How many people do you have working on the farm?
("Part-time" persons are ok, e.g. 3½)

Number of staff: _____

10. What animal species other than pigs are present on the piggery and in close proximity to buildings containing pigs?

Horses
Cattle
Sheep
Deer
None

Dogs
Cats
Domestic fowl
Wild birds

Other Please specify: _____

11. How you dispose of dead pigs, piglets and afterbirth?

Please tick the boxes that apply on your farm.

On Farm		Off Farm	
Rubbish pit	<input type="checkbox"/>	Rubbish pit	<input type="checkbox"/>
Burial	<input type="checkbox"/>	Burial	<input type="checkbox"/>
Incineration	<input type="checkbox"/>	Incineration	<input type="checkbox"/>
Carcasses fed to other animals	<input type="checkbox"/>	Carcasses fed to other animals	<input type="checkbox"/>
Offal hole	<input type="checkbox"/>	Offal hole	<input type="checkbox"/>
Rendered	<input type="checkbox"/>	Rendered	<input type="checkbox"/>
Composting	<input type="checkbox"/>	Composting	<input type="checkbox"/>

12. How long (on average) is a dead pig or piglet/afterbirth left in or near pig housing before it is disposed?

13. Which types of land-use are found within 500m of your piggery?

Please tick all that apply

Native bush/scrub
Forestry (eg plantation)
Livestock (Dairy, sheep & beef etc.)
Grain Crops
Non-grain Crops
Private houses

Other Please specify: _____

Rodent Activity

How often do you see evidence of rats and mice on your farm?

Please tick the box that best describes the occurrence of rats and mice on your farm.

		Regularly	Occasionally	Never
14.	Live rats on your farm	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15.	Dead rats on your farm	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16.	Rat droppings and holes in farm buildings	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17.	Live mice on your farm	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18.	Dead mice on your farm	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19.	Mouse droppings and holes in farm buildings	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

20. Are rats widespread throughout the piggery, or are they found in just one location within the piggery?

Widespread
Localised

21. What type of places do you see rats (if you see them) on your farm? (e.g. In pig pens, around the sump, in the feed room) _____

22. Do the rodent numbers on your farm fluctuate in different seasons?

Yes
No

23. Approximately how many cats do you have living on the piggery?

Number of cats: _____

Rodent Control

24. What are all the types of rodent control you use on your piggery?

- Professional pest control
 Traps – Live Capture or Snap Traps
 Poison baits
 Cats or Dogs
 None
 Other **Please specify:** _____

25. How often (eg, weekly, monthly etc) do you lay out poison to target rats and mice on your piggery? _____

26. Roughly how many bait stations are on your farm?

27. Which brand or brands of bait do you use?

- Pestoff
 Contrac
 Ditrac
 Racumin
 Talon
 Storm
 Kiwicare: No Rats & Mice
 Baraki rodenticide
 Other

28. Approximately how many rats per month do you catch in traps?

_____ / month

29. When you find dead rodents on your farm, do you:

- Leave them where they are lying
 Dispose of them

If so, how? _____

Trichinella

30. Have you heard of a parasite called *Trichinella*?

Yes
No

31. How do you believe people are most likely to become infected by *Trichinella*?

Drinking contaminated water
Eating or handling raw or poorly cooked beef
Eating or handling raw or poorly cooked pork or bacon
Gardening
Playing with the dog
Don't know

32. How do you think *Trichinella* can infect pigs?

Drinking contaminated water
Eating meat scraps
Scavenging dead rodents
Scavenging dead cats
By eating grain
By being kept in warm crowded housing
Don't know

Please write any further opinions and ideas that you would like to add on this subject in the space below.

Thank-you very much for participating in this survey, your time and knowledge is greatly appreciated

Appendix 3.2 – Thank-you letter

ADDRESS

10 November 2004

Dear *farmer name*

Thank-you very much for returning the questionnaire on commercial piggeries that I sent to you in October.

I really appreciate that you have taken time out from your busy day to fill in my survey form. Every form I get back adds important information to that whole New Zealand picture. I have been absolutely thrilled with the response that I have received and over 60% of you have replied so far! For a postal survey this is an excellent response rate and a credit to the industry.

The surveys are still being processed and the results will be ready for release early next year.

I hope you have a very Merry Christmas and a successful 2005.

Best wishes,

Esther Richardson
Epicentre
Institute of Veterinary, Animal, and Biomedical Sciences
Massey University
Private Bag 11-222
Palmerston North
phone (wk): 06 350 4008
email: e.richardson@massey.ac.nz

Appendix 3.3 - Raw data

The following pages contain all the raw data collated from the farm management questionnaire forms.

FarmID	NoOfSowsMatedGilt	NoOfUnmatedGilt	NoOfWeaners	NoOfGrowers	NoOfFinishers	AgeWeanerMin	AgeWeanerMax	AgeGrowerMin	AgeGrowerMax	AgeFinisherMin	AgeFinisherMax	Dry_Pens	Dry_Eco-shelters	Dry_Stalls
112	370	90	480	360	1200	4	8	8	11	8	20	1	0	1
113	255	30	700	700	600	4	10	10	16	16	21	1	0	1
114	220	19	524	227	351	28	74	74	97	97	137	0	0	1
1112	-1	-1	450	550	250	3	7	7	18	18	22	0	0	0
1113	100	12	230	165	291	4	10	11	15	16	20	0	0	1
1114	0	0	500	1000	500	-1	-1	-1	-1	-1	-1	0	0	0
1115	150	15	350	260	0	5	10	10	18	0	0	1	0	1
1117	600	60	2000	2000	1000	-1	-1	-1	-1	-1	-1	1	1	1
1118	0	0	550	524	498	4	10	11	15	15	20	0	0	0
1119	250	30	660	440	660	4	10	10	14	14	20	1	0	0
1120	220	10	500	1000	700	-1	-1	1000	-1	270	-1	1	0	1
1121	200	30	700	760	-1	4	10	-1	-1	10	20	0	0	0
1122	675	75	780	700	621	-1	-1	-1	-1	-1	-1	1	0	1
1126	120	15	250	300	310	4	8	8	15	15	21	0	0	0
1127	30	50	400	350	600	3	0	7	12	-1	-1	1	0	1
1129	179	6	400	400	400	0	10	10	16	16	23	1	0	0
1131	176	15	580	473	458	3	10	11	16	16	23	1	0	1
1132	65	-1	210	100	78	-1	-1	-1	-1	-1	-1	0	0	0
1134	35	25	800	800	700	4	-1	12	17	17	21	1	0	0
1135	1144	102	2016	418	415	4	8	12	-1	16	-1	0	0	0
1137	265	8	500	100	100	1	4	10	16	17	23	0	0	0
1139	420	17	700	1600	-1	4	9	-1	-1	10	20	0	0	0
1142	-1	-1	800	800	800	-1	-1	-1	-1	-1	-1	0	0	0
1144	130	10	420	360	390	4	11	11	16	16	-1	1	0	1
1145	95	7	180	370	810	0	4	4	11	12	21	0	1	1
1148	160	10	200	600	200	-1	-1	-1	-1	-1	-1	1	0	0
1149	135	6	120	430	650	-1	-1	-1	-1	-1	-1	1	0	1
1150	150	12	268	325	364	4	10	11	15	16	22	0	0	1
1152	-1	-1	300	300	300	-1	-1	-1	-1	-1	-1	0	0	0
1153	-1	-1	1400	-1	-1	12	-1	-1	-1	-1	-1	0	0	0
1154	130	20	250	300	300	-1	-1	-1	-1	-1	-1	1	0	0
1155	450	40	950	1425	2223	4	8	9	14	15	24	1	0	1
1157	120	12	250	200	-1	4	10	-1	-1	-1	-1	1	0	0
1158	90	6	300	550	550	-1	-1	-1	-1	-1	-1	0	0	0
1159	140	20	180	220	180	5	8	8	11	11	14	0	0	0
1160	0	0	1600	400	400	-1	-1	-1	-1	-1	-1	0	0	0
1161	95	8	479	261	119	0	9	10	16	17	21	1	0	1
1162	240	12	480	24	-1	-1	-1	-1	-1	-1	-1	0	0	0
1164	220	10	700	300	250	1	10	11	16	17	21	1	0	1
1166	290	30	520	800	800	-1	-1	-1	-1	-1	-1	1	0	0
1167	240	8	100	680	450	1	10	11	15	16	20	1	0	1
1169	250	10	720	900	-1	4	11	-1	-1	12	20	1	0	1
1170	330	16	600	-1	-1	6	8	-1	-1	-1	-1	1	0	1
1171	280	20	800	800	800	0	7	7	14	14	22	0	1	0
1172	1021	128	367	2844	-1	4	12	12	-1	-1	-1	1	0	0
1174	300	20	500	-1	-1	4	8	-1	-1	-1	-1	0	0	0
1175	400	30	1085	1500	-1	4	12	-1	-1	-1	-1	1	0	1
1176	170	12	450	350	250	5	12	16	16	16	21	0	0	0
1179	420	80	960	920	240	-1	-1	-1	-1	-1	-1	1	1	1
1181	280	20	900	600	400	4	10	-1	-1	-1	-1	1	0	1
1182	124	10	195	205	482	4	8	8	12	12	-1	0	0	1
1183	230	29	450	500	500	-1	-1	-1	-1	-1	-1	0	0	0
1184	2000	20	400	400	400	1	10	-1	17	-1	22	1	0	1
1185	235	21	160	1187	525	0	4	5	17	17	22	1	0	0
1186	246	10	556	440	420	4	10	10	16	16	20	0	1	0
1187	117	18	360	620	0	4	10	10	22	0	0	1	0	1
1189	270	30	750	750	500	-1	-1	-1	-1	-1	-1	1	0	1
1191	230	11	720	700	200	4	12	12	20	20	-1	1	0	0
1192	116	8	591	262	116	5	12	12	20	20	24	1	0	0
1193	100	20	250	200	-1	-1	-1	-1	-1	-1	-1	0	0	0
1196	2800	150	4500	6000	5000	4	8	9	14	15	19	0	0	0
1198	900	212	2383	2413	2526	-1	-1	-1	-1	-1	-1	1	0	0
1200	135	45	190	240	556	4	8	8	12	12	18	1	0	1
1202	155	15	520	300	380	4	12	12	16	16	22	0	1	0
1204	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0
1206	0	0	900	720	720	-1	-1	-1	-1	-1	-1	0	0	0
1208	320	39	1309	570	690	-1	-1	-1	-1	-1	-1	1	0	1
1210	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0
1211	150	20	600	300	300	-1	-1	-1	-1	-1	-1	1	0	0
1212	141	32	267	380	-1	-1	-1	-1	-1	-1	-1	1	0	0
1213	234	10	600	400	500	-1	-1	-1	-1	-1	-1	0	0	0
1215	0	0	600	200	-1	3	8	-1	-1	8	22	0	0	0
1216	191	24	415	321	586	-1	-1	-1	-1	-1	-1	1	0	1
1219	204	40	400	640	400	-1	-1	-1	-1	-1	-1	1	0	0
1221	136	12	560	255	180	-1	-1	-1	-1	-1	-1	1	0	1
1222	380	20	650	1110	700	4	9	9	17	17	22	0	0	0
1223	250	20	650	415	1200	4	10	11	14	14	22	1	0	1
1224	190	40	375	375	450	4	9	10	15	16	21	0	0	0
1225	350	30	1000	1000	1200	-1	-1	-1	-1	-1	-1	1	0	1
1226	300	20	600	600	600	-1	-1	-1	-1	-1	-1	0	0	0
1227	225	40	880	440	500	-1	-1	-1	-1	-1	-1	1	0	1
1231	-1	-1	-1	750	650	-1	-1	-1	-1	-1	-1	0	0	0
1232	330	42	120	60	60	4	10	16	16	16	20	0	0	0
1233	110	15	150	300	200	-1	-1	-1	-1	-1	-1	1	0	1
1234	152	20	340	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0

FarmID	Dry Outdoors	Dry_Other	Lactating Solar	Lactating Arc	Lactating Crate	Lactating Other	Grower Shed Weaners	Grower Shed Growers	Grower Shed Finishers	Grower Shelter Weaners	Grower Shelter Growers	Grower Shelter Finishers	Grower Kennels	Grower Weaner Boxes
112	0	0	0	0	1	0	1	1	1	0	1	0	0	0
113	0	0	0	0	1	0	1	1	1	0	0	0	0	1
114	0	0	0	0	1	0	0	1	1	1	0	0	0	0
1112	0	0	0	0	0	0	0	1	1	0	0	0	0	1
1113	0	0	0	0	1	0	1	1	0	0	0	1	0	0
1114	0	0	0	0	0	0	0	1	1	0	0	0	0	1
1115	0	0	0	0	1	0	1	1	0	0	0	0	0	0
1117	0	0	0	0	0	1	1	1	1	0	1	1	0	0
1118	0	0	0	0	0	0	0	1	1	0	0	0	0	1
1119	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1120	0	0	0	0	1	0	1	1	1	0	0	0	0	1
1121	1	0	0	1	0	0	0	1	1	0	0	0	1	0
1122	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1126	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1127	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1129	0	0	0	0	1	0	1	0	0	1	1	0	0	0
1131	0	0	0	0	1	0	0	1	1	1	0	0	0	0
1132	1	0	0	1	0	0	1	1	1	0	0	0	0	0
1134	0	0	0	0	1	0	0	1	1	0	0	0	1	1
1135	1	0	0	1	0	0	0	0	0	0	1	1	1	0
1137	1	0	0	0	0	1	1	1	1	0	0	0	0	0
1139	1	0	0	1	0	0	0	0	0	0	0	0	0	1
1142	0	0	0	0	0	0	1	1	1	1	1	1	0	0
1144	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1145	0	0	1	0	1	0	0	1	1	0	1	1	0	1
1148	0	0	0	0	0	1	1	0	0	0	1	1	0	0
1149	0	0	0	0	1	0	0	1	1	1	0	0	0	0
1150	1	0	0	0	1	0	0	0	1	0	0	0	1	0
1152	0	0	0	0	0	0	1	1	1	0	0	0	0	0
1153	0	0	0	0	0	0	1	1	1	0	0	0	0	0
1154	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1155	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1157	1	0	0	0	1	0	1	1	1	0	0	0	0	0
1158	1	0	0	0	1	0	1	1	1	0	0	0	0	0
1159	1	0	0	1	0	0	0	0	0	1	1	1	0	0
1160	0	0	0	0	0	0	1	1	1	1	1	1	0	0
1161	0	0	0	0	1	0	1	0	1	1	1	1	0	0
1162	1	0	0	0	0	1	0	0	0	0	1	0	1	0
1164	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1166	0	0	0	0	1	0	0	0	0	1	1	1	0	0
1167	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1169	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1170	0	0	0	1	1	0	0	0	0	0	0	0	0	1
1171	1	0	0	1	0	0	0	1	1	1	1	0	0	0
1172	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1174	1	0	0	1	0	0	0	0	0	0	0	0	0	1
1175	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1176	1	0	0	0	1	0	0	1	1	1	0	0	0	0
1179	0	0	0	0	1	0	1	1	1	0	1	1	0	0
1181	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1182	0	0	0	0	1	0	0	1	1	0	0	0	0	1
1183	1	0	0	1	0	0	0	1	1	1	0	0	1	0
1184	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1185	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1186	0	0	0	0	1	0	0	1	1	1	0	0	0	0
1187	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1189	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1191	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1192	1	0	1	0	0	0	0	1	1	1	1	0	0	1
1193	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1196	1	0	0	1	0	0	0	0	1	1	1	0	0	0
1198	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1200	0	0	0	0	1	0	0	1	1	0	0	0	0	1
1202	1	0	0	0	0	1	0	1	1	1	0	0	0	0
1204	0	0	0	0	0	0	1	1	1	0	0	0	1	0
1206	0	0	0	0	0	0	1	1	1	0	0	0	0	0
1208	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1210	0	0	0	0	0	0	1	1	1	0	0	0	0	0
1211	0	0	0	0	1	0	0	1	1	0	0	0	0	1
1212	0	0	0	0	1	0	0	1	1	0	0	0	0	1
1213	1	0	0	1	0	0	1	1	1	0	0	0	0	0
1215	0	0	0	0	0	0	1	1	1	0	0	0	0	0
1216	0	0	0	0	1	0	1	0	0	0	1	1	0	1
1219	0	1	0	0	1	0	1	1	1	1	0	0	0	0
1221	0	0	0	0	1	0	0	1	1	0	0	0	0	1
1222	1	0	0	1	0	0	0	1	1	1	0	0	0	0
1223	0	0	0	0	1	0	0	1	1	1	0	0	0	1
1224	1	0	0	1	0	0	0	1	1	1	0	0	0	1
1225	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1226	1	0	0	1	0	0	0	1	1	1	0	0	0	0
1227	0	0	0	0	1	0	1	1	1	0	1	0	0	0
1231	0	0	0	0	0	0	0	1	1	0	0	0	0	0
1232	1	0	0	1	0	0	0	0	0	0	1	1	1	0
1233	0	0	0	0	1	0	1	1	1	0	0	0	0	0
1234	1	0	0	1	0	0	0	0	0	0	0	0	1	0

FarmID	Building AgeMin	Building AgeMax	MillMixFood	Feed Comound Feed	FeedGrain	FeedMeat BoneMeal	Feed BloodMeal	FeedSoy	Feed FishMeal	FeedOther	FeedGrain Source OnFarm
112	2	30	1	1	1	1	1	1	1	1	Off Farm
113	13	60	1	0	1	1	1	1	1	0	Off Farm
114	1	25	1	0	1	1	1	1	1	1	On Farm
1112	5	30	1	0	1	1	1	1	1	0	and Off
1113	15	25	1	0	1	1	1	1	1	0	Off Farm
1114	10	30	1	0	1	0	0	0	0	1	Off Farm
1115	10	30	1	0	0	1	1	1	1	0	None
1117	1	50	1	1	1	1	1	1	1	1	Off Farm
1118	1	30	1	1	1	1	1	1	1	0	Off Farm
1119	3	12	0	1	0	0	0	0	0	0	None
1120	30	45	1	0	1	1	1	1	1	0	Off Farm
1121	1	10	1	0	1	1	1	1	1	0	Off Farm
1122	4	50	0	0	0	1	1	1	0	0	None
1126	5	45	1	0	1	1	1	1	1	0	and Off
1127	15	30	1	0	1	1	1	1	0	0	None
1129	4	50	1	0	1	1	1	1	1	0	Off Farm
1131	5	40	1	0	1	1	1	1	1	0	Off Farm
1132	20	35	1	0	1	1	0	0	0	0	Off Farm
1134	1	85	1	0	1	1	1	1	1	1	None
1135	2	10	1	1	0	0	0	0	0	1	Off Farm
1137	15	105	1	0	1	1	1	1	1	1	On Farm
1139	17	17	0	1	0	0	0	0	0	0	None
1142	4	35	0	1	0	0	0	0	0	0	Off Farm
1144	2	22	0	1	0	0	0	0	0	0	None
1145	6	32	1	0	1	1	1	1	0	0	Off Farm
1148	2	25	1	0	1	1	0	1	0	0	On Farm
1149	2	40	1	0	1	1	0	1	0	0	and Off
1150	5	40	1	0	1	1	1	1	1	1	Off Farm
1152	10	25	1	0	1	1	1	1	1	0	Off Farm
1153	-1	-1	0	1	0	0	0	0	0	0	None
1154	21	28	1	0	0	1	1	0	0	1	None
1155	5	60	1	0	1	1	0	1	1	0	Off Farm
1157	5	20	1	1	1	0	0	0	0	0	Off Farm
1158	10	30	1	1	1	1	0	0	0	0	Off Farm
1159	2		1	0	1	1	1	1	1	1	Off Farm
1160	3	10	1	0	1	1	1	1	1	0	and Off
1161	3	26	1	0	1	1	1	1	1	0	Off Farm
1162	10	10	0	1	0	0	0	0	0	0	None
1164	10	25	0	1	0	0	0	0	0	0	None
1166	3	30	1	1	1	1	1	1	1	1	and Off
1167	30	50	0	1	0	0	0	0	0	1	None
1169	4	25	1	0	1	1	1	1	1	1	Off Farm
1170	1	10	0	1	0	0	0	0	0	1	None
1171	1	25	1	1	1	1	1	1	1	0	and Off
1172	-1	-1	1	0	1	1	1	1	0	0	and Off
1174	10	20	1	0	1	1	1	0	0	0	Off Farm
1175	20	20	1	0	1	1	1	1	1	1	Off Farm
1176	10	50	1	0	1	1	0	1	1	1	Off Farm
1179	1	30	0	1	1	1	1	1	1	0	Off Farm
1181	10	10	1	0	1	1	1	1	0	1	Off Farm
1182	-1	-1	1	0	1	1	1	1	1	0	Off Farm
1183	2	10	0	1	0	0	0	0	0	0	Off Farm
1184	1	30	1	0	1	1	0	1	1	0	and Off
1185	9	30	1	0	1	0	0	1	1	1	Off Farm
1186	2	50	0	1	0	0	0	0	0	1	None
1187	10	50	1	1	1	1	0	0	0	0	On Farm
1189	10	50	1	0	1	1	1	1	1	1	Off Farm
1191	3	50	1	0	1	1	1	1	1	1	Off Farm
1192	-1	-1	1	0	1	1	1	1	1	0	On Farm
1193	10	10	1	1	1	1	1	1	1	1	Off Farm
1196	10	10	0	1	0	0	0	0	0	0	None
1198	2	35	1	0	1	1	1	1	1	0	Off Farm
1200	10	50	1	0	1	1	1	1	1	1	On Farm
1202	2	25	1	0	1	1	1	1	1	1	Off Farm
1204	12	20	1	0	1	1	1	1	1	0	Off Farm
1206	10	40	1	0	1	1	0	1	0	0	Off Farm
1208	1	15	1	1	1	1	1	1	1	1	Off Farm
1210	10	50	1	0	0	0	0	0	0	1	Off Farm
1211	5	30	1	0	1	1	1	1	1	0	Off Farm
1212	-1	-1	0	0	0	1	1	1	1	0	None
1213	12	12	1	1	1	1	1	1	1	0	Off Farm
1215	10	16	0	1	0	0	0	0	0	0	None
1216	8	20	0	1	0	0	0	0	0	0	None
1219	5	30	1	0	1	1	1	1	1	0	Off Farm
1221	12	25	1	0	1	1	1	1	1	0	On Farm
1222	20	20	0	1	0	0	0	0	0	0	Off Farm
1223	5	25	1	0	1	1	1	1	1	0	Off Farm
1224	5	11	1	0	1	1	1	1	1	0	On Farm
1225	4	35	1	0	1	1	1	1	1	0	None
1226	1	30	1	1	1	1	1	1	1	0	and Off
1227	15	30	1	0	1	1	1	1	1	1	Off Farm
1231	20	40	1	0	1	1	1	1	1	1	and Off
1232	5	10	0	1	0	0	0	0	0	0	None
1233	22	40	1	0	1	1	1	1	1	1	and Off
1234	9	9	1	1	1	1	0	0	0	0	On Farm

FarmID	Feed Other Source OnFarm	FeedOtherSpecify	ByProd Bread	ByProdBake	ByProd Domestic	ByProd Unrendered Meat	ByProd Dairy	ByProd Other	ByProd None	MethodWet	MethodDry	MethodMix
112	None	Tallow Milk Powder	1	0	0	0	0	0	0	1	1	0
113	None		0	0	0	0	0	0	1	0	0	1
114	None	Soya oil tallow	0	0	0	0	0	0	1	0	1	0
1112	None		0	0	0	0	0	0	1	0	0	1
1113	None		0	0	0	0	0	0	1	0	0	1
1114	None	mix protien	0	1	0	0	0	0	0	1	0	0
1115	Off Farm		1	0	1	0	0	0	0	0	0	1
1117	None	milk powder soyamed tallow	0	0	0	0	0	0	1	0	1	0
1118	None		0	0	0	0	0	0	1	0	0	1
1119	None		0	0	0	0	0	0	1	0	1	0
1120	None		0	0	0	0	1	0	0	1	0	0
1121	None		0	0	0	0	0	0	0	0	1	0
1122	None		0	0	0	0	0	0	1	0	0	1
1126	None		0	0	0	0	0	0	1	0	0	1
1127	None		0	1	0	0	1	0	0	0	0	0
1129	Off Farm		0	0	0	0	0	0	1	0	0	1
1131	None		0	0	0	0	0	0	1	0	0	1
1132	None		0	0	0	0	0	0	1	0	1	0
1134	None	Milk powder	0	0	1	0	1	0	0	0	0	1
1135	Off Farm		1	1	0	0	0	1	0	0	0	1
1137	On Farm	Milk powder	0	0	0	0	0	0	0	0	1	0
1139	None		0	0	0	0	0	0	1	0	1	0
1142	None		0	0	0	0	0	0	1	0	0	1
1144	None		0	0	0	0	0	0	1	0	1	0
1145	None		0	0	0	0	0	0	1	0	1	0
1148	None		0	0	0	0	0	0	1	0	1	0
1149	None		0	0	0	0	0	0	1	0	1	0
1150	None	Milk powder	1	0	0	0	0	0	0	0	1	0
1152	None		0	0	0	0	0	0	1	0	1	0
1153	None		0	0	0	0	1	0	0	1	1	0
1154	None	bread and whey	1	0	0	0	1	0	0	0	0	1
1155	None		0	0	0	0	1	0	0	1	0	0
1157	None		0	0	0	0	0	0	1	0	0	1
1158	None		0	0	0	0	0	0	1	0	0	1
1159	Off Farm	chips	0	0	0	0	0	1	0	0	1	0
1160	None		0	0	0	0	0	0	0	0	0	1
1161	None		0	0	0	0	0	0	1	0	1	0
1162	None		0	0	0	0	0	0	0	0	1	0
1164	None		0	0	0	0	0	0	1	0	1	0
1166	None	Milk powder	0	0	0	0	0	0	1	0	0	1
1167	None	whey	0	0	0	0	1	0	0	0	0	1
1169	None	Milk powder	0	0	0	0	1	0	0	0	0	1
1170	None		1	0	0	0	1	0	0	0	0	1
1171	None	Milk	0	0	0	0	0	0	1	0	0	1
1172	None		0	0	0	0	1	0	0	1	0	1
1174	None		0	0	1	0	0	0	0	0	1	0
1175	Off Farm	Milk powder, food waste	1	1	1	1	1	0	0	0	0	0
1176	Off Farm		0	0	0	0	0	0	1	0	0	1
1179	None		0	0	0	0	0	0	1	0	1	0
1181	On Farm	Milk	0	0	0	0	1	0	0	1	0	0
1182	None		0	0	0	0	0	0	1	0	0	1
1183	None		0	0	0	0	0	0	1	0	1	0
1184	Off Farm		0	0	0	0	1	0	0	1	0	0
1185	Off Farm	milk powder	0	0	0	0	0	0	0	0	0	1
1186	Off Farm	Milk By product (whey)	0	0	0	0	1	0	0	0	0	1
1187	None		0	0	0	0	0	0	1	0	0	1
1189	Off Farm	milk powder	0	0	0	0	0	1	0	0	0	1
1191	None	Proliq (from lactose)	0	0	0	0	0	1	0	1	0	0
1192	None	Milk powder, tallow and chese for all.	0	0	0	0	0	0	0	0	0	1
1193	None		1	0	0	0	1	0	0	0	1	0
1196	None		0	0	0	0	0	0	1	0	1	0
1198	None		0	0	0	0	0	1	0	0	0	1
1200	None	Milk powder tallow	0	0	0	0	0	0	1	0	0	1
1202	Off Farm	and Broll	0	0	0	0	1	1	0	1	0	0
1204	None		0	0	0	0	0	0	1	0	0	1
1206	None		0	0	0	0	0	0	0	0	0	1
1208	Off Farm	Milk Powder	0	0	0	0	0	0	1	0	0	1
1210	None	norm mataua (pellets)	0	0	0	0	0	0	1	0	0	1
1211	None		0	0	0	0	0	0	1	0	1	0
1212	None		0	1	0	0	1	0	0	0	0	1
1213	None		0	0	0	0	0	0	1	0	1	0
1215	None		0	0	0	0	0	0	0	0	1	0
1216	None		0	0	0	0	0	0	1	0	1	0
1219	Off Farm		0	0	0	0	0	0	0	0	0	1
1221	None		0	0	0	0	0	0	0	0	1	0
1222	None		0	0	0	0	0	0	1	0	0	1
1223	None		0	0	0	0	0	0	1	0	0	1
1224	None		0	0	0	0	0	0	0	0	1	0
1225	None		0	0	0	0	0	0	1	0	0	1
1226	None		0	0	0	0	0	0	1	0	1	0
1227	Off Farm	Bread	1	0	0	0	0	0	0	1	0	1
1231	Off Farm	thremine, soy oil	0	0	0	0	0	0	1	0	1	0
1232	None		0	0	0	0	0	0	1	0	1	0
1233	Off Farm	meal.	0	0	0	0	0	0	1	0	1	0
1234	None		0	0	0	0	0	0	1	0	1	0

FarmID	Unmilled Wooden Pallets	Unmilled Loose Stacked	Unmilled Silos	Unmilled Bins	Unmilled Other	Unmilled Not Applicable	Ingredients Wooden Pallets	Ingredients Loose Stacked	Ingredients Silos	Ingredients Bins	Ingredients Other	Ingredients Not Applicable	Mixed Wooden Pallets	Mixed Loose Stacked
112	0	0	0	0	1	0	1	0	0	0	0	0	0	0
113	0	0	1	0	0	0	1	0	1	0	0	0	0	0
114	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1112	0	0	1	0	0	0	0	0	1	0	0	0	0	0
1113	0	0	1	0	0	0	1	0	0	0	0	0	0	1
1114	0	0	1	0	0	0	1	1	1	0	0	0	0	0
1115	0	0	0	0	0	0	0	1	0	0	0	0	0	0
1117	0	0	1	1	0	0	0	0	1	0	0	0	0	0
1118	0	0	1	0	0	0	1	0	0	0	0	0	1	0
1119	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1120	1	0	1	0	0	0	1	1	0	0	0	0	0	0
1121	0	0	1	0	0	0	1	1	0	0	0	0	0	0
1122	1	0	0	0	0	0	0	0	0	0	0	0	1	0
1126	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1127	0	0	1	0	0	0	1	0	0	1	0	0	0	0
1129	0	0	1	0	0	0	1	0	1	0	0	0	0	0
1131	0	0	1	0	0	0	1	1	1	0	0	0	0	0
1132	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1134	0	0	1	0	0	0	1	1	1	0	0	0	0	0
1135	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1137	0	1	1	0	0	0	0	1	0	0	0	0	0	0
1139	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1142	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1144	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1145	0	0	1	0	0	0	1	1	0	0	0	0	0	0
1148	0	0	1	0	0	0	0	1	0	0	0	0	0	0
1149	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1150	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1152	0	0	1	0	0	0	0	1	0	0	0	0	0	0
1153	0	0	1	0	0	0	0	0	1	0	0	0	0	0
1154	0	0	0	1	0	0	0	1	0	0	0	0	0	0
1155	0	0	1	0	0	0	1	0	0	0	0	0	0	1
1157	0	0	1	0	0	0	1	0	1	0	0	0	0	0
1158	0	0	1	0	0	0	0	1	1	0	0	0	0	1
1159	0	0	1	0	0	0	0	1	0	0	0	0	0	1
1160	0	0	1	0	0	0	1	1	0	0	0	0	1	1
1161	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1162	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1164	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1166	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1167	0	0	1	0	0	0	0	0	0	0	0	0	0	0
1169	0	0	1	0	0	0	1	0	0	0	1	0	0	0
1170	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1171	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1172	0	0	1	0	0	0	0	0	1	0	0	0	0	0
1174	0	0	1	0	0	0	0	1	0	0	0	0	0	0
1175	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1176	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1179	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1181	0	0	1	0	0	0	0	0	1	0	0	0	0	0
1182	0	0	1	0	0	0	1	0	1	0	0	0	0	0
1183	0	0	0	0	0	0	0	0	0	0	0	0	0	1
1184	0	0	1	0	0	0	1	0	1	0	0	0	0	0
1185	0	0	1	0	0	0	1	0	1	0	0	0	1	0
1186	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1187	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1189	0	0	1	0	0	0	1	0	0	0	1	0	0	0
1191	0	0	1	0	0	0	1	0	0	1	0	0	0	0
1192	0	0	1	0	0	0	0	0	0	0	1	0	0	0
1193	0	0	1	1	0	0	0	1	0	0	0	0	0	0
1196	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1198	0	0	1	0	0	0	0	0	1	0	0	0	0	0
1200	0	0	1	1	0	0	1	1	0	0	0	0	0	0
1202	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1204	0	0	1	0	0	0	1	0	0	0	0	0	0	1
1206	0	0	1	0	0	0	1	0	0	0	0	0	0	1
1208	0	0	1	0	0	0	1	0	1	0	0	0	0	0
1210	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1211	0	0	1	0	0	0	1	1	0	0	0	0	0	0
1212	0	0	0	0	0	1	0	1	1	0	0	0	0	0
1213	0	0	1	0	0	0	1	0	0	0	0	0	1	0
1215	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1216	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1219	0	0	1	0	0	0	0	1	0	0	0	0	0	0
1221	1	0	1	0	0	0	0	0	1	0	0	0	0	0
1222	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1223	0	0	1	0	0	0	0	0	1	0	1	0	0	0
1224	0	0	1	0	0	0	1	0	0	0	0	0	1	0
1225	0	0	0	0	1	0	0	0	1	0	0	0	0	0
1226	0	0	1	0	0	0	0	0	1	0	0	0	0	0
1227	0	0	1	0	0	0	1	0	0	0	0	0	0	0
1231	0	0	1	0	0	0	1	1	0	0	0	0	0	0
1232	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1233	0	0	1	0	0	0	0	1	0	0	0	0	0	1
1234	0	0	1	0	0	0	0	1	0	0	0	0	1	1

FarmID	MixedSilos	MixedBins	MixedOther	Mixed Not Applicable	Staff Numbers	Animal Horses	Animal Cattle	Animal Sheep	AnimalDeer	AnimalDogs	AnimalCats	Animalfowl	Animal Wildbirds	AnimalNone
112	0	1	0	0	6	0	1	0	0	1	1	1	1	0
113	1	1	0	0	8	0	1	0	0	1	1	0	1	0
114	1	1	0	0	3	1	1	1	0	0	0	0	0	0
1112	1	0	0	0	2	0	0	1	0	1	1	0	0	0
1113	0	0	0	0	3	0	0	1	0	1	1	0	1	0
1114	0	0	0	0	3	0	0	0	0	1	1	0	0	0
1115	1	0	0	0	3.5	0	1	0	0	0	0	1	0	0
1117	1	0	0	0	9	0	1	0	0	0	1	0	1	0
1118	1	1	0	0	2	0	1	1	0	0	1	0	1	0
1119	1	0	0	0	5.5	0	0	1	0	0	1	0	1	0
1120	1	0	0	0	3.5	0	1	0	0	0	1	0	1	0
1121	1	0	0	0	1	0	1	1	0	1	1	0	0	0
1122	1	0	0	0	6	0	0	1	0	0	0	0	0	0
1126	1	0	0	0	3.5	0	1	0	0	0	0	0	0	0
1127	1	0	0	0	4.5	0	1	0	0	1	1	0	0	0
1129	1	0	0	0	1.5	0	1	0	0	0	1	0	0	0
1131	1	0	0	0	2	0	1	1	0	1	0	0	0	0
1132	1	0	0	0	1	0	1	1	0	1	1	0	1	0
1134	1	0	0	0	4	0	0	0	0	0	0	0	0	1
1135	1	1	0	0	27	0	0	0	0	0	1	0	1	0
1137	1	0	0	0	2.5	0	0	1	0	1	1	0	1	0
1139	1	0	0	0	4	0	1	1	0	1	0	0	1	0
1142	1	0	0	0	1.5	0	1	0	0	0	0	0	0	0
1144	1	1	0	0	2	0	1	0	0	1	1	0	0	0
1145	0	1	0	0	2	0	0	1	0	1	1	0	0	0
1148	1	0	0	0	4	0	1	1	0	1	1	1	0	0
1149	0	1	0	0	1.5	0	1	0	0	1	1	0	1	0
1150	1	0	0	0	0	0	1	1	0	0	1	1	1	0
1152	1	0	0	0	0	0	1	0	0	1	0	0	0	0
1153	1	0	0	0	2	0	0	1	0	0	0	0	0	0
1154	0	0	0	0	4	1	1	1	0	1	1	0	1	0
1155	1	0	0	0	6.5	0	1	0	0	0	1	0	1	0
1157	1	0	0	0	2	0	0	0	0	0	0	0	0	1
1158	1	0	0	0	1	0	1	0	0	1	1	0	1	0
1159	0	0	0	0	2	0	0	1	0	1	1	0	1	0
1160	1	0	0	0	2	0	1	1	0	1	1	0	0	0
1161	1	0	0	0	1.5	0	1	0	0	1	0	0	1	0
1162	1	0	1	0	3	0	0	1	0	1	1	1	0	0
1164	1	0	0	0	3	0	0	0	0	0	0	0	1	1
1166	1	0	0	0	5	0	1	1	0	1	1	0	1	0
1167	1	0	0	0	3	0	1	1	0	0	1	0	0	0
1169	1	0	0	0	4	0	1	0	0	1	0	0	0	0
1170	1	0	0	0	4	0	0	0	0	0	1	0	0	0
1171	1	0	1	0	3.5	0	1	0	0	1	1	0	1	0
1172	1	0	0	0	15	0	0	1	0	0	0	0	0	0
1174	1	0	0	0	1	0	1	0	0	1	1	1	1	0
1175	0	1	0	0	6	0	1	0	0	1	0	1	0	0
1176	1	0	0	0	2.5	0	0	0	0	1	0	0	0	0
1179	0	1	0	0	5	0	0	1	0	0	1	0	1	0
1181	1	0	0	0	2	0	0	0	0	0	0	0	0	1
1182	1	0	0	0	2	0	1	0	0	1	1	0	0	0
1183	1	0	0	0	2	1	1	1	0	0	0	0	0	0
1184	1	0	0	0	2	1	0	1	0	1	0	0	1	0
1185	1	0	0	0	3.5	1	1	1	0	0	0	0	0	0
1186	1	0	0	0	4	0	1	0	0	0	0	0	0	0
1187	0	0	0	0	1.5	0	1	1	0	0	1	0	1	0
1189	1	1	0	0	4.5	0	1	1	0	0	1	0	1	0
1191	1	1	0	0	4	0	1	1	0	1	1	0	0	0
1192	0	0	0	0	2	0	0	1	0	1	0	0	1	0
1193	0	1	0	0	2	0	0	0	0	1	1	1	1	0
1196	1	0	0	0	40	0	0	0	0	0	1	0	1	0
1198	0	1	0	0	18	0	1	0	0	0	1	0	0	0
1200	1	1	0	0	2	0	0	1	0	1	1	0	1	0
1202	1	0	0	0	2	0	1	0	0	0	0	0	1	0
1204	1	0	0	0	4	0	1	0	0	0	0	0	0	0
1206	1	1	0	0	2	0	0	1	0	0	1	0	0	0
1208	1	0	0	0	4	0	0	1	0	0	0	0	0	0
1210	1	0	0	0	1	1	1	0	0	1	1	0	0	0
1211	1	0	0	0	2.5	0	1	0	0	1	1	0	1	0
1212	0	0	0	1	1	0	1	1	0	0	0	0	0	0
1213	0	0	0	0	2.5	0	1	1	0	0	1	0	1	0
1215	1	0	0	0	1	0	0	1	0	0	0	0	0	0
1216	1	0	0	0	2	0	0	1	0	1	1	0	0	0
1219	1	0	0	0	4.5	0	0	0	0	1	0	1	1	0
1221	0	0	0	0	3	0	1	0	0	1	1	0	0	0
1222	1	0	0	0	4	0	0	0	0	0	0	0	1	1
1223	1	0	0	0	3	0	0	1	0	0	0	1	0	0
1224	0	0	0	0	2	0	1	0	0	0	0	0	0	0
1225	1	0	0	0	4	0	1	1	0	1	1	1	0	0
1226	0	1	0	0	3	0	0	0	0	1	0	0	1	0
1227	1	0	0	0	5	1	1	0	0	1	1	0	1	0
1231	0	1	0	0	1.25	0	1	1	0	1	1	1	1	0
1232	1	0	0	0	2	0	1	0	0	1	1	0	0	0
1233	0	0	0	0	3	0	1	0	0	0	0	0	1	0
1234	1	1	0	0	1	0	1	1	0	1	0	1	1	0

FarmID	AnimalOther	AnimalOther Specify	OnRubbish Pit	OnBurial	On Incineration	On Other Animals	OnOffalHole	On Rendered	On Composting	Off Rubbish Pit	OffBurial	Off Incineration	Off Other Animals	Off Offal Hole
112	1	Mice	0	0	0	0	0	0	1	0	0	0	0	0
113	0		0	0	0	0	1	0	1	0	0	0	0	0
114	0		0	0	0	0	0	0	1	0	0	0	0	0
1112	0		0	0	0	0	1	0	0	0	0	0	0	0
1113	0		0	0	0	0	1	0	0	0	0	0	0	0
1114	0		0	0	0	0	0	0	1	0	0	0	0	0
1115	0		0	0	1	0	1	0	0	0	0	0	0	0
1117	1	mice rats	0	0	0	0	1	0	1	0	0	0	0	0
1118	0		0	0	0	0	1	0	0	0	0	0	0	0
1119	0		0	0	0	0	1	0	1	0	0	0	0	0
1120	0		0	1	0	0	0	0	0	0	0	0	0	0
1121	0		0	0	1	0	0	0	1	0	0	0	0	0
1122	0		0	0	0	0	0	0	1	0	0	0	0	0
1126	0		0	0	0	0	0	0	1	0	0	0	0	0
1127	0		0	0	0	0	0	0	1	0	0	0	0	0
1129	0		0	0	0	0	0	0	0	0	0	0	0	0
1131	0		0	1	0	0	1	0	0	0	0	0	0	0
1132	0		0	0	0	0	0	0	0	0	0	0	0	1
1134	0		0	0	0	0	0	0	1	0	0	0	0	0
1135	0		0	0	0	0	0	0	1	0	0	0	0	0
1137	0		0	0	0	0	1	0	0	0	0	0	0	1
1139	1	Rodents	0	0	0	0	1	0	0	0	0	0	0	0
1142	0		0	0	0	0	0	0	1	0	0	0	0	0
1144	0		0	1	1	0	1	0	0	0	0	0	0	0
1145	0		0	0	0	0	1	0	0	0	0	0	0	0
1148	0		0	0	0	0	1	0	0	0	0	0	0	0
1149	0		0	0	0	0	1	0	0	0	0	0	0	0
1150	0		0	0	0	0	0	0	1	0	0	0	0	0
1152	0		0	0	0	0	1	0	0	0	0	0	0	0
1153	0		0	0	0	0	0	0	1	0	0	0	0	0
1154	0		0	0	0	0	1	0	0	0	0	0	0	0
1155	0		0	0	0	0	1	0	0	0	0	0	0	0
1157	0		0	1	0	0	0	0	0	0	0	0	0	0
1158	0		0	0	0	0	1	0	0	0	0	0	0	0
1159	0		0	0	0	0	0	0	1	0	0	0	0	0
1160	0		0	0	0	0	1	0	0	0	0	0	0	0
1161	0		0	0	1	0	0	0	1	0	0	0	0	0
1162	0		0	0	0	0	0	0	1	0	0	0	0	0
1164	1	rabbits	0	1	0	0	0	0	0	0	0	0	0	0
1166	0		0	0	0	0	0	0	1	0	0	0	0	0
1167	0		0	0	0	0	1	0	0	0	0	0	0	0
1169	0		0	0	0	0	0	0	1	0	0	0	0	0
1170	0		0	0	0	0	0	0	1	0	0	0	0	0
1171	0		0	0	0	0	1	0	0	0	0	0	0	0
1172	0		0	0	0	0	0	0	1	0	0	0	0	0
1174	0		0	0	0	0	1	0	0	0	0	0	0	0
1175	0		0	0	0	0	1	1	1	0	0	0	0	0
1176	0		0	0	0	0	1	0	0	0	0	0	0	0
1179	0		0	0	0	0	0	0	1	0	0	0	0	0
1181	0		0	1	0	0	0	0	0	0	0	0	0	0
1182	0		0	0	0	0	1	0	0	0	0	0	0	0
1183	0		0	0	0	0	1	0	0	0	0	0	0	0
1184	0		0	0	0	0	1	0	0	0	0	0	0	0
1185	0		0	0	0	0	0	0	1	0	0	0	0	0
1186	0		0	0	0	0	0	0	1	0	0	0	0	0
1187	0		0	0	0	0	1	0	0	0	0	0	0	0
1189	0		0	0	0	0	0	0	1	0	0	0	0	0
1191	0		0	0	0	0	1	0	0	0	0	0	0	0
1192	0		0	0	0	0	0	0	1	0	0	0	0	0
1193	0		0	0	0	0	1	0	0	0	0	0	0	0
1196	0		0	0	0	0	0	0	1	0	0	0	0	0
1198	0		0	0	0	0	1	0	0	0	0	0	0	0
1200	0		0	1	0	0	1	0	0	0	0	0	0	0
1202	0		0	0	0	0	0	0	1	0	0	0	0	0
1204	0		0	0	0	0	1	0	0	0	0	0	0	0
1206	0		0	0	0	0	1	0	0	0	0	0	0	0
1208	0		0	1	0	0	0	0	0	0	0	0	0	0
1210	0		0	0	0	0	1	0	0	0	0	0	0	0
1211	0		0	0	0	0	0	0	1	0	0	0	0	0
1212	0		0	0	0	0	1	0	0	0	0	0	0	0
1213	0		0	0	0	0	1	0	0	0	0	0	0	0
1215	0		0	0	0	0	0	0	0	0	0	0	0	0
1216	0		0	0	0	0	0	0	1	0	0	0	0	0
1219	0		0	0	0	0	1	0	0	0	0	0	0	0
1221	0		0	0	0	0	0	0	1	0	0	0	0	0
1222	0		0	0	0	0	1	0	0	0	0	0	0	0
1223	0		0	0	0	0	0	0	1	0	0	0	0	0
1224	0		0	0	0	0	1	0	0	0	0	0	0	0
1225	0		0	0	0	0	1	0	0	0	0	0	0	0
1226	0		0	0	0	0	1	0	0	0	0	0	0	0
1227	0		0	0	0	0	0	0	1	0	0	0	0	0
1231	0		1	0	0	0	0	0	0	0	0	0	0	0
1232	0		0	0	0	0	1	0	0	0	0	0	0	0
1233	0		0	0	1	0	0	0	0	0	0	0	0	0
1234	0		0	0	0	0	1	0	1	0	0	0	0	0

FamID	Off Rendered	Off Composting	Time To Dispose	LandUse NativeBush	LandUse Forestry	LandUse Livestock	LandUse Grain	LandUse NonGrain	LandUse Private	LandUse Other	LandUse Other Specify	LiveRats	DeadRats
112	0	0	1 day	0	0	1	0	0	1	1	Golf Course	1	1
113	0	0	hours	1	0	1	0	0	1	0		1	1
114	0	0	days	0	0	1	0	0	1	0		1	1
1112	0	0	1 day	0	0	1	1	1	0	0		1	1
1113	0	0		0	0	1	0	0	1	0		1	2
1114	0	0		0	0	0	0	1	1	0		0	0
1115	0	0	1 day	1	1	1	0	0	0	0		1	1
1117	0	0	18 hours	0	1	1	0	0	0	0		1	1
1118	0	0	8 hours	0	0	1	0	0	0	0		1	1
1119	0	0	day	0	1	1	0	0	0	0		1	1
1120	0	0		0	0	1	0	0	0	0		1	1
1121	0	0	0.5 Day	0	1	1	0	0	1	0		1	1
1122	0	0	day	0	1	0	0	0	1	0		1	1
1126	0	0	days	0	0	0	1	0	0	0		1	1
1127	0	0	daily	1	0	0	0	0	0	1	Ponds/streams	1	2
1129	0	1	1 day	0	0	1	0	0	1	0		1	1
1131	0	0	2 Days	0	0	1	0	0	1	0		1	1
1132	0	0	0	0	0	1	0	0	1	0		1	0
1134	0	0	Daily	0	0	0	0	0	1	1	Creek	1	1
1135	0	0	day	0	0	1	0	0	0	0		1	1
1137	0	0	1.5 Days	0	0	1	1	0	1	0		1	1
1139	0	0	Day	0	1	1	0	0	1	0		2	2
1142	0	0	1 hour	0	0	1	0	1	1	0		1	1
1144	0	0	2 hours	0	0	1	0	0	1	0		1	
1145	0	0	2 days	0	0	1	0	0	1	0		1	1
1148	0	0	2 Days	0	0	1	1	0	0	0		1	0
1149	0	0	1 day	0	0	1	1	0	1	0		1	1
1150	0	0	1 day	0	0	1	0	0	1	0		1	1
1152	0	0	daily	0	0	1	0	0	1	0		1	1
1153	0	0	Daily	0	0	1	0	0	0	0		1	1
1154	0	0	Daily	1	0	1	0	0	1	0		1	1
1155	0	0	3	0	0	1	0	0	0	0		1	1
1157	0	0	Day	0	0	1	0	0	1	1	Deer, horses	1	1
1158	0	0	0	0	1	1	0	0	0	0		1	1
1159	0	0	6 hours	1	0	1	0	0	0	0		1	0
1160	0	0	1-2 hours	0	0	1	1	0	0	0		1	1
1161	0	0	2 hours	0	1	1	0	0	1	0		1	1
1162	0	0	Day	0	1	1	1	0	1	0		1	1
1164	0	0	2 hours	0	1	1	0	0	0	0		0	0
1166	0	0	1 day	0	0	1	1	0	0	0		1	1
1167	0	0	2 hours	0	0	1	0	0	0	0		1	1
1169	0	0	0.3 Days	0	1	1	0	0	1	0		1	1
1170	0	0	Day	0	0	1	1	0	0	0		1	1
1171	0	0	1 day	0	0	1	1	0	1	0		1	1
1172	0	0	up daily	0	0	1	0	0	0	0		1	1
1174	0	0	1 day	0	0	1	0	0	0	0		1	1
1175	0	0	Day	0	1	1	0	0	0	0		1	1
1176	0	0		0	0	1	0	0	0	0		1	1
1179	0	0	1 day	0	0	1	0	0	0	0		1	1
1181	0	0	1.5 days	0	0	1	0	0	0	0		1	1
1182	0	0	0.5 Days	0	0	1	0	0	1	0		1	0
1183	0	0	0.5 Day	0	0	1	1	0	0	0		1	1
1184	0	0	minutes	0	0	1	1	1	1	0		1	1
1185	0	0	1 day	0	0	1	1	0	0	0		1	1
1186	0	0	hours	0	0	1	0	0	1	0		1	1
1187	0	0	1 day	1	1	1	1	1	1	0		0	0
1189	0	0	1 day	0	0	1	0	0	0	1	shelter belts (Quinfoss)	1	1
1191	0	0	0	0	1	1	0	0	1	1		1	1
1192	0	0	Day	0	0	1	0	0	1	0		1	1
1193	0	0	0	0	0	1	1	1	0	0		1	1
1196	0	0	Day	0	1	1	0	0	0	0		0	0
1198	0	0	0.5 day	0	0	1	0	0	0	0		1	1
1200	0	0	2 Days	1	1	1	1	1	1	0		1	1
1202	0	0	0.5 Days	1	1	1	0	0	1	1	Kiwi fruit orchards	1	1
1204	0	0	2 Days	0	0	1	0	0	1	0		1	1
1206	0	0	less day	0	0	1	0	0	1	0		0	0
1208	0	0	3 Days	0	0	1	0	0	0	0		1	1
1210	0	0	daily	0	0	1	0	0	0	0			
1211	0	0	0.5 day	0	0	0	1	1	1	0		1	
1212	0	0	0	0	0	1	0	0	0	0		0	0
1213	0	0	a day	0	0	1	1	1	0	0		2	1
1215	0	1	Day	0	0	0	0	0	1	1	properties	1	1
1216	0	0	2 Days	1	0	1	0	0	1	0		1	1
1219	0	0	1.5	0	0	1	0	1	0	0		2	1
1221	0	0	2 - 3 days	0	1	1	1	0	1	0		1	1
1222	0	0	0.5 days	0	0	1	0	0	1	1	Lifestyle block	1	1
1223	0	0	day	0	0	1	0	0	0	0		1	1
1224	0	0	Day	0	0	0	1	0	0	0		1	1
1225	0	0	12 hours	0	0	1	0	0	1	0		1	1
1226	0	0	10 mins	0	0	0	1	0	0	0		0	1
1227	0	0	ss week	0	1	1	0	0	1	0		1	1
1231	0	0	hours	0	0	1	1	1	1	0		1	1
1232	0	0	6 hours	0	1	1	0	0	1	0		1	1
1233	0	0	2 Days	0	0	1	1	0	0	0		1	1
1234	0	0	1 Day	0	0	1	1	0	0	0		1	0

FarmID	Rat Droppings	LiveMice	DeadMice	Mouse Droppings	RatLocation	CommonRatLocations	Rodent Numbers Fluctuate	CatNumbers	FeralCats	Number FeralCats
112	2	1	1	1	0	cavity.	Yes	4		
113	1	0	0	1	0	In drians, under slats.	Yes	1	No	
114	1	2	2	2	0	around one open drian	Yes	0		
1112	1	1	1	2	0	The Sump	Yes	3		
1113	1	1	2	1	1	around sawdust deep litre	Yes	2		0
1114	0	1		2			Yes	0		
1115	1	0	0	0	0	sump and feed room	Yes	2		0
1117	1	1	1	1	1	feed shed	Yes	3		0
1118	1	1	1	1	1	Around the feed room	No	1		0
1119	2	1	1	2	1	outside of buildings	Yes	3		0
1120	1	1	1	1	1	feed room and pig pens	No	3		0
1121	1	2	2	2	0	Hay sheds and farm buildings.	Yes	1		
1122	1	2	2	2	0	In pens	Yes	0		0
1126	1	1	1	1	0	Manure drains	No	0	No	0
1127		0	0	0	1	Meal shed	Yes	3		0
1129	1	0	0	0	1	pump shed by river		3		0
1131	1	2	2	2	0	Farrowing Rooms	Yes	0		
1132	1	0	0	0	0	Walk ways	No	5		
1134	1	1	1	1	1	Outside sheds	Yes	6		0
1135	1	0	0	0	1	outside in the field	No	0	Yes	12
1137	2	0	1	2	0	Feed room and weaner shed	Yes	6		
1139	1	2	2	1	1	and hanging around the offal	Yes	0		
1142	1	1	1	1	1	seldom seen	Yes	4		0
1144	0	1	1	2	0	SUMP	Yes	3		0
1145	2	1	1	1	0	litter shed.	No	5		
1148	1	1	0	1	0	Feed room, milling shed.	No	4		
1149	1	0	0	0	0		No	2	No	0
1150	1	1	1	1	0	round stump	Yes	1		
1152	1	2				Pig shed	Yes	0	No	0
1153	1	1	1	1	1		Yes	0		
1154	2	1	0	0	1	raceway	Yes	3		0
1155	0	1	0	0	0	sump	No	15		0
1157	1	2	2	2	0	Diggings outside	Yes	0	Yes	3
1158	1	1	1	1	0	localised place.	Yes	6		
1159	1	1	1	1	0	In roof and under straw	Yes	3		0
1160	1	1	1	1	0	around sumps	Yes	5		0
1161	1	1	1	1	0	automated feed units	Yes	0	No	0
1162	2	1			1	keunds and farrowing		0	Yes	
1164	0	0	0	0				0		0
1166	1	1	1	1	1	Outside buildings	Yes	6		0
1167	1	1	1	1	0	room		1		0
1169	2	1	1	2	1	grower shed.		0	Yes	3
1170	1	1	1	1	0	buildings.	Yes	0	Yes	6
1171	1	2	1	2	1	Everywhere	Yes	0	Yes	0
1172	1	1	1	1	1	In around buildings	Yes	0		
1174	1	1	1	1	1	Any place.	Yes	6		
1175	1	2	2	2	0	major building with a concrete	Yes	10		
1176	1	2	1	2	0	Pig feeding area	Yes	4		0
1179	1	1	1	1	0	Pig pens	Yes	0	Yes	0
1181	2	1	1	1	1	Feed room	No	2		0
1182	1	2	0	1	0	Don't see them.	Yes	0		
1183	1	1	1	1	1	shifted.	Yes	0	Yes	3
1184	1	2	1	2	0	offal pit and older sheeds	No	0	No	0
1185	1	2	2	2	1	pig pens	Yes	3		0
1186	1	1	1	1	0	Effluent stump.	Yes	6		
1187	0	1	1	1			Yes	3		0
1189	1	1	1	2	1	sump	Yes	0	Yes	0
1191	1	1			0	Around pig pens.	No	10		
1192	1	2	1	2	0	Feed room	No	0	Yes	
1193	0	1	1	0		killed it (hunt went on for an	Yes	6		
1196	1	1	1	1	0	Under feeder platforms	Yes	15		
1198	1	1	1	1	1	Around the sump	No	20		0
1200	1	2	1	2	1	feed room and grain sheds.	Yes	0	Yes	4
1202	2	1	0	0	1	feeding troughs in outdoor	Yes	1		
1204	1	1	1	1	0	In pig pens.	Yes	4		
1206	1	1	1	1		In walk ways	Yes	4		0
1208	1	1	1	1	0	Effluent Lines.	Yes	0		
1210		1					No	2		0
1211	1	2	2	2	0	buildings	Yes	3		0
1212	0	0	0	0		Around pond.	Yes	0		
1213	1	2	1	1	0	haysheds effluent channels	Yes	0	Yes	6
1215	1	2	0	1	0	floor	Yes	2		
1216	2	1	1	2	1	banks.		3	Yes	3
1219	1	2	1	2	1	Sump and Back of sheds.	Yes	0	Yes	2
1221	2	2	2	2	1	Paths, Pens and Drains	Yes	2		
1222	2	1	1	2	0	outside of concrete		0		0
1223	1	2	1	1	0	Sump, compost, pig pens	Yes	2	No	0
1224	1	1	0	0	0	see them near puddles when	No	0	Yes	3
1225	1	1	1	1	0	Pig pens	Yes	5		0
1226	1	1	1	1	1	Do not see.	Yes	0		
1227	1	1	1	1	0	foundations.	Yes	8		
1231	1	1	1	1	0	in pig house or nearby outside	No	2		0
1232	1	1	1	1	1	We do not see many rats	Yes	2	No	0
1233	1	2	2	1		Out doors.	Yes	0		
1234	1	2	0	1	1	and cozy kennels.	No	0		

FarmID	PestControl	Traps	Poison baits	CatsDogs	None	Other Control	Control Other Specify	PoisonLay Frequency	BaitStation Number	PestOff	Contract	Ditrac	Racumin	Talon	Storm
112	0	0	1	0	0	0		2 weeks	30	0	0	1	0	0	0
113	0	0	1	1	0	1	4x2	Monthly	150	0	1	0	0	0	0
114	0	0	1	0	0	0		Daily	0	0	0	0	1	0	0
1112	0	0	1	0	0	0		monthly	10	0	0	0	1	0	0
1113	0	0	1	0	0	0		0.5	0	0	0	0	0	1	0
1114	0	0	1	0	0	0		Annually	7	0	0	0	0	1	0
1115	0	0	1	0	0	0		weekly	18	0	0	0	0	0	0
1117	0	0	1	1	0	0		monthly	15	1	0	0	0	1	0
1118	1	0	1	1	0	0		monthly	20	0	0	0	0	0	0
1119	0	1	1	0	0	0		monthly	20	0	0	0	0	1	1
1120	0	0	1	1	0	0			0	0	0	0	1	1	1
1121	0	0	1	1	0	0		required	4	0	0	0	0	1	1
1122	1	0	0	0	0	0		Monthly	42	0	0	0	0	1	0
1126	0	0	1	0	0	0		Weekly	5	0	0	0	0	1	1
1127	0	0	1	0	0	0		weekly	15	0	0	0	1	1	0
1129	0	0	1	1	0	0		Monthly	10	0	0	0	0	1	0
1131	0	0	1	1	0	0		Weekly	0	0	0	0	1	1	1
1132	0	0	1	1	0	0		Weekly	8	0	0	0	1	0	0
1134	0	0	1	0	0	0		Monthly	20	0	0	0	0	1	0
1135	0	0	0	0	1	0		n/a	0	0	0	0	0	0	0
1137	1	0	1	1	0	0		Weekly	12	0	0	0	1	1	0
1139	0	1	1	0	0	0		Weekly	10	0	0	0	0	0	1
1142	0	0	1	0	0	0		Monthly	6	0	0	0	0	1	1
1144	0	0	1	1	0	1	STATION	weekly	3	1	0	0	0	0	0
1145	0	0	1	1	0	0		ally	6	0	0	0	0	0	1
1148	0	0	0	1	0	0		0	0	0	0	0	0	0	0
1149	0	0	0	1	0	0		never	0	0	0	0	0	0	0
1150	0	0	1	1	0	0		see signs	5	1	0	0	0	1	0
1152	0	0	1	0	0	0		monthly	6	0	0	0	1	0	0
1153	0	0	1	0	0	0		Weekly	5	0	1	0	1	1	1
1154	0	0	1	1	0	0		required	0	0	0	0	0	1	0
1155	0	0	1	1	0	0		2 weeks	12	1	0	0	0	0	0
1157	0	0	1	0	0	0		Weekly	5	0	0	0	1	1	1
1158	0	0	1	1	0	0		Monthly	0	0	0	0	0	1	1
1159	0	0	0	1	0	0		never	0	0	0	0	0	0	0
1160	0	0	1	1	0	0			10	0	0	0	1	0	1
1161	0	0	1	0	0	0		weekly	12	0	0	0	1	1	1
1162	0	0	1	0	0	0		t	0	0	0	0	0	0	1
1164	0	0	1	0	0	0		2 weeks	50	0	1	0	0	0	0
1166	0	0	1	0	0	0		weekly	20	1	0	0	0	0	0
1167	0	0	1	0	0	0		weekly	90	0	1	0	0	0	0
1169	0	0	1	0	0	0		Mounths	4	0	0	0	0	1	1
1170	0	0	1	1	0	1	shooting	Monthly	30	0	0	0	1	1	1
1171	0	0	1	1	0	0		onthly	6	0	0	0	0	0	1
1172	0	1	1	0	0	0		Weekly	10	0	1	0	1	1	1
1174	0	0	1	1	0	0		month	6	0	0	0	0	0	1
1175	0	0	1	0	0	1	(rarely)	Weekly	20	0	0	0	0	1	0
1176	0	0	1	1	0	0		monthly	4	0	0	0	0	1	0
1179	0	0	1	0	0	0		onthly	30	1	0	0	0	1	0
1181	0	0	1	0	0	0		weeks	0	0	0	0	0	0	1
1182	0	1	1	0	0	0		6 Weekly	10	0	0	0	0	1	1
1183	0	0	1	0	0	0		Monthly	6	0	0	0	1	0	1
1184	0	0	1	0	0	0		monthly	0	0	0	0	0	1	1
1185	0	0	1	1	0	0		6 weeks	30	0	0	0	0	1	1
1186	0	0	1	1	0	0		fortnightl	6	0	0	0	1	0	1
1187	0	0	1	1	0	0		weekly	10	0	0	0	1	0	1
1189	0	0	1	1	0	0		ly	10	0	0	0	0	1	1
1191	0	0	1	1	0	0		Daily	4	1	0	0	0	1	0
1192	0	1	1	1	0	0		Monthly	5	0	0	0	1	1	1
1193	0	1	1	1	0	0		3 Months	15	0	0	0	1	0	0
1196	0	0	1	0	0	0		Not often	3	0	0	0	0	1	1
1198	0	0	0	1	0	0		No	0	0	0	0	0	0	0
1200	0	1	1	1	0	0		Weekly	4	0	0	0	1	1	1
1202	0	0	1	0	0	0		Weekly	8	0	0	0	1	1	1
1204	0	0	1	1	0	0		week	8	0	0	0	1	0	1
1206	0	0	1	0	0	0		monthly	18	0	0	0	1	0	0
1208	0	0	1	0	0	0		Weekly	0	1	0	0	0	1	0
1210	0	0	1	1	0	0		monthly	20	0	0	0	1	0	0
1211	0	0	1	1	0	0		weeks	10	0	0	0	0	1	0
1212	0	0	1	0	0	0		Weekly	16	0	0	0	0	1	0
1213	0	0	1	1	0	0		months	2	0	0	0	1	0	1
1215	0	0	1	0	0	0		Monthly	0	0	0	0	0	1	1
1216	0	0	1	0	0	0		Monthly	40	1	0	0	0	1	0
1219	0	0	1	0	0	0		Monthly	10	0	0	0	0	1	1
1221	0	0	1	0	0	0		Monthly	15	0	0	0	0	1	0
1222	0	0	1	1	0	0		Monthly	0	0	0	0	0	1	1
1223	0	0	1	0	0	0		required	10	0	0	0	1	1	0
1224	0	0	1	0	0	0		Monthly	6	0	0	0	1	1	1
1225	0	0	1	0	0	0		weekly	0	1	0	0	0	1	1
1226	0	1	1	0	0	0		Monthly	15	1	0	0	1	1	1
1227	0	0	1	1	0	0		required	8	0	0	0	0	1	0
1231	0	0	1	1	0	0		monthly	0	0	0	0	0	1	0
1232	0	0	1	1	0	0		monthly	0	0	0	0	0	1	1
1233	0	1	1	0	0	0		'as	6	0	0	0	0	1	0
1234	0	0	1	1	0	0		y	1	0	0	0	0	0	1

FarmID	Kiwicare	Baraki	OtherBrand	RatsCaught	DeadRodent Disposal	RodentDisposal	Trichinella	HeardOf Trichinella	People Water	PeopleBeef
112	0	0	0	0	them	Compost.	112	1	0	0
113	0	0	0	0	them	But if rotten and old	113	1	0	0
114	0	0	0	0	them	compost	114	1	0	0
1112	0	0	0	2	Leave them		1112	0	0	0
1113	0	0	0	0	them	Offal hole	1113	1	0	0
1114	0	0	0	0	them	Compost	1114	0	0	0
1115	0	0	1	0	them	Incinerate	1115	1	0	0
1117	0	0	0	0	them	offal pit	1117	1	0	0
1118	0	0	0	0	them	offal	1118	1	0	0
1119	0	0	0	0	Leave them		1119	1	0	0
1120	0	0	0	0	them	offal hole	1120	1	0	0
1121	0	0	0	0	Leave them		1121	1	0	0
1122	0	0	0	0	them	or bury them	1122	1	1	0
1126	0	0	0	0			1126	0	0	0
1127	0	0	0	0	them	the bush	1127	1	0	0
1129	0	0	0	0	them	rubbish	1129	1	0	0
1131	0	0	0	0	them	takes them if he	1131	1	0	0
1132	0	0	0	0	Leave them	N/A	1132	1	0	0
1134	0	0	0	0	them	Compost	1134	1	0	0
1135	0	0	0	0			1135	1	0	0
1137	0	0	0	0	Leave them		1137	0	0	0
1139	0	0	0	1	them	in Offal hole	1139	1	0	0
1142	0	0	0	0			1142	1	0	0
1144	0	0	0	0	them	burn them	1144	1	0	0
1145	0	0	0	0	them	piggery compound.	1145	1	0	0
1148	0	0	0	0	them	Offal hole	1148	1	1	0
1149	0	0	0	0		never see any	1149	0	0	0
1150	0	0	0	0	them	Burn	1150	1	0	0
1152	0	0	0	0	them	sumps	1152	1	0	0
1153	0	0	0	0	them	Compost	1153	1	0	0
1154	0	0	0	0	them	not given	1154	1	0	0
1155	0	0	0	0			1155	1	0	0
1157	0	0	0	0	them	Burial	1157	1	0	0
1158	0	0	0	0	them	Offal hole	1158	1	0	0
1159	0	0	0	0	them	compost	1159	1	0	0
1160	0	0	0	0	them	offal hole	1160	1	0	0
1161	0	0	0	0	them	bury or incerate	1161	1	0	0
1162	0	0	0	0	them	for survey	1162	1	0	0
1164	0	0	0	0	them	offal pit	1164	1	0	0
1166	0	0	0	0	Leave them		1166	1	0	0
1167	0	0	0	0	them	offal pit	1167	1	0	0
1169	0	0	0	0	them	Rubbish bin	1169	1	0	0
1170	0	0	0	0	them	no answer	1170	1	0	0
1171	0	0	0	0	them	Offal hole	1171	1	0	0
1172	0	0	0	20	them	compost	1172	1	0	0
1174	0	0	0	0	them	offal hole.	1174	0	0	0
1175	0	0	0	0	them	Offal hole.	1175	1	0	0
1176	0	0	0	0	them	offal	1176	0	1	0
1179	0	0	0	0	them	Composting	1179	1	0	0
1181	0	0	0	0	them	bury	1181	1	0	0
1182	0	0	0	2	them	Burn	1182	1	0	0
1183	0	0	0	0	them	Compost	1183	0	0	0
1184	0	0	0	0	them	pit	1184	1	0	0
1185	0	0	0	0	them	compost	1185	1	0	0
1186	0	0	0	0	them	compost bin.	1186	1	0	0
1187	0	0	0	0	them	offal pir	1187	1	0	0
1189	0	0	0	0	them	Put in dead drum	1189	1	0	0
1191	0	0	0	0	them	Offal hole	1191	1	0	0
1192	0	0	0	3	them	Compost	1192	1	0	0
1193	0	0	0	0	them	Burn	1193	0	0	0
1196	0	0	0	0	them	Compost	1196	1	0	0
1198	0	0	0	0	them	offal pit	1198	1	0	0
1200	1	0	0	3	them	Offal hole or burial	1200	0	0	0
1202	0	0	0	0	them	Compost	1202	1	0	0
1204	0	0	0	0	Leave them		1204	1	0	0
1206	0	0	0	0			1206	1	0	0
1208	0	0	0	0	them	Burial	1208	1	0	0
1210	1	1	0	0	them	burn	1210	0	0	0
1211	0	0	0	0	them	compost	1211	1	0	0
1212	0	0	0	0	them	Offal hole	1212	0	0	0
1213	0	0	0	0	them	offal pit	1213	1	1	0
1215	0	0	0	2	them	Buried	1215	0	0	0
1216	0	0	0	0	them	Compost	1216	1	0	0
1219	0	0	0	0	them	Offal hole	1219	1	0	0
1221	0	0	0	0	them	Compost	1221	1	0	0
1222	0	0	0	0	them	rodenets	1222	1	0	0
1223	0	0	0	0	them	Compost	1223	1	0	0
1224	0	0	0	0	them	Offal hole	1224	0	0	0
1225	0	0	0	0	them	Offal pit	1225	1	0	0
1226	0	0	0	0	them	offal hole	1226	1	0	0
1227	0	0	0	0	them	Compost	1227	0	0	0
1231	0	0	0	0	Leave them		1231	1	0	0
1232	0	0	0	0	them	Offal hole	1232	1	0	0
1233	0	0	0	1	them	Incinerate	1233	1	0	0
1234	0	0	0	0	them	Offal hole	1234	1	0	0

FarmID	People Bacon	People Gardening	People Dog	People NotSure	PigWater	PigMeat Scrap	PigDead Rodents	PigDead Cats	PigGrain	PigHousing	PigNotSure
112	1	0	0	0	0	0	1	0	0	0	0
113	1	0	0	0	0	0	1	1	0	0	0
114	1	0	0	0	0	0	1	0	0	0	0
1112	0	0	0	1	0	0	0	0	0	0	1
1113	0	0	0	1	0	0	0	0	0	0	1
1114	1	0	0	0	0	0	1	0	0	0	0
1115	1	0	0	0	0	1	1	0	0	0	0
1117	1	0	0	0	0	1	0	0	0	0	0
1118	1	0	0	0	0	1	1	1	0	0	0
1119	0	0	0	1	0	0	0	0	0	0	1
1120	1	0	0	0	0	1	1	1	0	0	0
1121	0	0	0	1	0	0	0	0	0	0	1
1122	0	1	0	0	1	0	0	1	0	0	0
1126	0	0	0	1	0	0	0	0	0	0	1
1127	1	0	0	0	0	1	1	1	0	0	0
1129	0	0	0	1	0	0	1	0	0	0	0
1131	1	0	0	0	0	0	0	0	0	0	1
1132	1	0	0	0	0	0	1	0	0	0	0
1134	1	0	0	0	0	1	0	0	0	0	0
1135	1	0	0	0	0	1	1	0	0	0	0
1137	0	0	0	1	0	0	0	0	0	0	1
1139	1	0	0	0	0	1	1	0	0	0	0
1142	1	0	0	0	0	0	1	0	0	0	0
1144	0	0	0	1	0	0	0	0	0	0	1
1145	1	0	0	0	0	0	1	0	0	0	0
1148	1	0	0	0	1	1	1	0	0	0	0
1149	0	0	0	1	0	0	0	0	0	0	1
1150	1	0	0	0	0	1	1	0	0	0	0
1152	0	0	0	1	0	0	1	0	0	0	0
1153	1	0	0	0	0	1	1	1	0	0	0
1154	0	0	0	0	0	0	0	0	0	0	0
1155	1	0	0	0	0	1	0	0	0	0	0
1157	0	0	0	1	0	0	0	0	0	0	1
1158	1	0	0	0	0	0	1	0	0	0	0
1159	1	0	0	0	0	0	1	0	0	0	0
1160	1	0	0	0	0	0	1	0	0	0	0
1161	1	0	0	0	0	0	1	0	0	0	0
1162	0	0	0	1	0	0	0	0	0	0	1
1164	1	0	0	0	0	0	1	0	0	0	0
1166	1	0	0	0	0	0	1	0	0	0	0
1167	1	0	0	0	0	0	1	0	0	0	0
1169	1	0	0	0	0	0	1	0	0	0	0
1170	0	0	0	1	0	0	0	0	0	0	0
1171	0	0	0	1	0	0	0	0	0	0	1
1172	1	0	0	0	0	1	1	1	0	0	0
1174	0	0	0	1	0	0	0	0	0	0	1
1175	1	0	0	0	0	0	1	0	0	0	0
1176	0	0	0	0	1	0	0	0	0	0	0
1179	0	0	0	1	0	0	1	0	0	0	0
1181	1	0	0	0	0	0	1	0	0	0	0
1182	0	0	0	1	0	0	0	0	0	0	1
1183	0	0	0	1	0	0	0	0	0	0	1
1184	1	0	0	0	0	1	1	0	0	0	0
1185	1	0	0	0	0	0	0	0	0	0	1
1186	1	0	0	0	0	1	1	0	0	0	0
1187	0	0	0	1	0	0	1	0	0	0	0
1189	1	0	0	0	0	1	1	1	0	0	0
1191	1	0	0	0	0	0	1	0	0	0	0
1192	0	0	0	1	0	0	0	0	0	0	1
1193	0	0	0	1	0	0	0	0	0	0	1
1196	1	0	0	0	0	0	1	0	0	0	0
1198	0	0	0	1	0	0	0	0	0	0	1
1200	0	0	0	1	0	0	0	0	0	0	1
1202	1	0	0	0	0	0	1	0	0	0	0
1204	1	0	0	0	0	0	0	0	0	0	1
1206	0	0	0	1	0	0	1	0	0	0	0
1208	1	0	0	0	0	0	1	1	0	0	0
1210	0	0	0	1	0	0	0	0	0	0	1
1211	1	0	0	0	0	1	1	0	0	0	0
1212	0	0	0	1	0	0	0	0	0	0	1
1213	1	0	0	0	1	0	1	0	0	0	0
1215	0	0	0	0	0	0	0	0	0	0	0
1216	1	0	0	0	0	0	1	0	0	0	0
1219	1	0	0	0	0	0	1	0	0	0	0
1221	1	0	0	0	0	1	1	0	0	0	0
1222	1	0	0	0	0	0	1	0	0	0	0
1223	1	0	0	0	0	0	1	0	0	0	0
1224	0	0	0	1	0	0	0	0	0	0	1
1225	1	0	0	0	0	0	1	0	0	0	0
1226	0	0	0	1	0	0	0	0	0	0	1
1227	0	0	0	1	0	0	0	0	0	0	1
1231	0	0	0	1	0	0	0	0	0	0	1
1232	1	0	0	0	0	0	0	1	0	0	0
1233	1	0	0	0	0	0	1	1	0	0	0
1234	0	0	0	1	0	0	0	0	0	0	1

Appendix 3.4- Results of univariate analysis comparing rat activity with on-farm variables

		P-value		% Response	(n)	P-value<0.2
		Chi-square test	Fisher's test			
Pig Housing						
Dry sows	Pens	0.869		52.90%	-85	NO
	Ecoshelters		0.338	7.10%	-85	NO
	Stalls	0.786		41.20%	-85	NO
	Outdoors		0.37	27.10%	-85	NO
	Other		0.197	1.20%	-85	YES
Lactating sows	Solari		0.358	2.40%	-85	NO
	Arc		1	18.80%	-85	NO
	Crate	0.855		61.20%	-85	NO
	Other	0.06		5.90%	-85	YES
Grower herd	ShedWeaners	0.6		57.60%	-85	NO
	ShedGrowers		1	23.50%	-85	NO
	ShedFinishers		0.48	82.40%	-85	NO
	ShelterWeaners		0.74	82.40%	-85	NO
	ShelterGrowers		1	22.40%	-85	NO
	ShelterFinishers		1	17.60%	-85	NO
	Kennels		0.679	10.60%	-85	NO
	WeanerBoxes		0.745	22.40%	-85	NO
Pig Feed						
Feed ingredients used	Mill/Mix own food		0.338	0.80%	-85	NO
	Compound Feed	0.537		36.50%	-85	NO
	Only Compound			20.00%	-85	NO
	Grain		0.205	92.60%	-68	NO
	MeatBoneMeal		0.511	94.10%	-68	NO
	BloodMeal	0.673		79.40%	-68	NO
	Soy		0.542	86.80%	-68	NO
	FishMeal	0.284		75.00%	-68	NO
By-products fed	Other	0.784		34.10%	-85	NO
	Bread		1	10.60%	-85	NO
	Bake		0.579	5.90%	-85	NO
	Domestic		0.579	4.70%	-85	NO
	UnrenderedMeat		1	1.20%	-85	NO
	Dairy		0.726	20.00%	-85	NO
	Other		1	7.10%	-85	NO
	None	0.406		54.10%	-85	NO
Feeding method used	Wet		0.447	12.90%	-85	NO
	Dry	0.161		41.20%	-85	YES
	Mix	0.108		48.20%	-85	YES

		P-value		% Response	(n)	P-value<0.2	
		Chi-square test	Fisher's test				
Feed storage method	Unmilled grain	WoodenPallets	0.488	3.50%	-85	NO	
		LooseStacked	0.197	1.20%	-85	YES	
		Silos	0.108	72.90%	-85	YES	
		Bins	1	4.70%	-85	NO	
		Other	0.358	2.40%	-85	NO	
	Mixed feed	WoodenPa	0.291		49.40%	-85	NO
		LooseStacked		1	27.10%	-85	NO
		Silos		0.211	25.90%	-85	NO
		Bins		1	2.40%	-85	NO
		Other		1	4.70%	-85	NO
	Mixed feed	NotApplica	0.869		0.00%	-85	NO
		WoodenPallets		1	8.20%	-85	NO
		LooseStacked		1	12.90%	-85	NO
		Silos		0.205	76.50%	-85	NO
		Bins		0.502	22.40%	-85	NO
		Other		0.358	2.40%	-85	NO
		NotApplicable		1	1.20%	-85	NO
Farm Environment	Other species in piggery					NO	
	Horses		1	8.20%	-85	NO	
	Cattle	0.128		62.40%	-85	YES	
	Sheep	0.617		48.20%	-85	NO	
	Deer	n/a	n/a	0.00%	-85	NO	
	Dogs	0.08		51.80%	-85	YES	
	Cats	0.687		60.00%	-85	NO	
	Fowl		0.696	14.10%	-85	NO	
	Wildbirds	0.244		48.20%	-85	NO	
	None		0.254	5.90%	-85	NO	
	Other		0.173	4.70%	-85	YES	
Animal disposal	On-farm	RubbishPit		1	1.20%	-85	NO
		Burial		1	9.40%	-85	NO
		Incineration		0.579	5.90%	-85	NO
		OtherAnim:	n/a	n/a	0.00%	-85	NO
		OffalHole	0.696		51.80%	-85	NO
		Rendered		1	1.20%	-85	NO
		Compostin:	0.873		42.40%	-85	NO
	Off-farm	RubbishPit	n/a	n/a	0.00%	-85	NO
		Burial	n/a	n/a	0.00%	-85	NO
		Incinerator	n/a	n/a	0.00%	-85	NO
		OtherAnim:	n/a	n/a	0.00%	-85	NO
		OffalHole		0.358	2.40%	-85	NO
		Rendered	n/a	n/a	0.00%	-85	NO
		Composting		1	2.40%	-85	NO

		P-value		% Response	(n)	P-value<0.2
		Chi-square test	Fisher's test			
Land-use surrounding piggery	NativeBush		0.188	10.60%	-85	YES
	Forestry		0.205	23.50%	-85	NO
	Livestock		0.334	89.40%	-85	NO
	Grain		1	28.20%	-85	NO
	NonGrain		1	12.90%	-85	NO
	Private	0.04		51.80%	-85	YES
	Other		0.188	10.60%	-85	YES
	Rodent Control					NO
	Types of rodent control					
	PestControl		0.488	3.50%	-85	NO
Traps		1	10.60%	-85	NO	
Poisonbaits		0.592	92.90%	-85	NO	
CatsDogs	0.163		48.20%	-85	YES	
None		1	1.20%	-85	NO	
OtherControl		1	4.70%	-85	NO	
Brand of toxic bait (if used)						
PestOff		0.677	13.30%	-83	NO	
Contrac		0.577	6.00%	-83	NO	
Ditrac		0.19	1.20%	-83	YES	
Racumin	0.204		33.70%	-83	NO	
Talon	0.855		61.40%	-83	NO	
Storm	0.291		49.40%	-83	NO	
Kiwicare		1	2.40%	-83	NO	
Baraki	n/a	n/a	1.20%	-83	NO	
OtherBrand		1	1.20%	-83	NO	
<i>Trichinella</i>						
Heard of <i>Trichinella</i>		0.281	82.40%	-85	NO	
Suspected source of human infection						
Water		1	4.80%	-83	NO	
Beef	n/a	n/a	0.00%	-83	NO	
Bacon	0.391		60.20%	-83	NO	
Gardening		1	1.20%	-83	NO	
Dog	n/a	n/a	0.00%	-83	NO	
NotSure	0.317		37.30%	-83	NO	
Suspected source of pig infection						
Water		1	4.90%	-81	NO	
MeatScrap		0.508	22.20%	-81	NO	
DeadRodents	0.284		59.30%	-81	NO	
DeadCats		0.198	13.60%	-81	YES	
Grain	n/a	n/a	0.00%	-81	NO	
Housing	n/a	n/a	0.00%	-81	NO	
NotSure	0.499		34.60%	-81	NO	

Appendix 4.1– Digitised aerial photos



Appendix 4.1. Figure 1 Digitised aerial photos of Piggery 1 with inside and outside monitoring tunnel locations.



Appendix 4.1. Figure 2 Digitised aerial photos of Piggery 2 with inside and outside monitoring tunnel locations.



Appendix 4.1. Figure 3 Digitised aerial photos of Piggery 3 with inside and outside monitoring tunnel locations.

Appendix 4.2 – Rat SAS Analysis

Below is a copy of the SAS code used to create a logistic regression model for investigating rat activity.

```
Proc genmod data = rats descending;

class week piggery shed pig_type shed_type tunnel inside
onground ;

model tracked= week piggery inside onground pig_type
shed_type / dist=bin type3 obstats;

repeated subject= tunnel(shed piggery)/type=ar(1);

ODS OUTPUT ObStats=obsts;

run;
```

What follows is a line by line breakdown of what the above SAS code is asking for:

`Proc genmod` is specifying the type of logistic regression analysis to use, in this case `Proc genmod` is used to analyse generalized linear models.

`"data = rats"` specifies the data table to use for the analysis, in this case the data table is called "rats".

`"Descending"` is used to specify the order of comparison for the Outcome variable, in this case `PROC GENMOD` is modelling the probability that `TRACKED='1'`. If `descending` was not specified, `PROC GENMOD` would model the probability that `TRACKED='0'` which would change the analysis to focus on non-activity rather than activity.

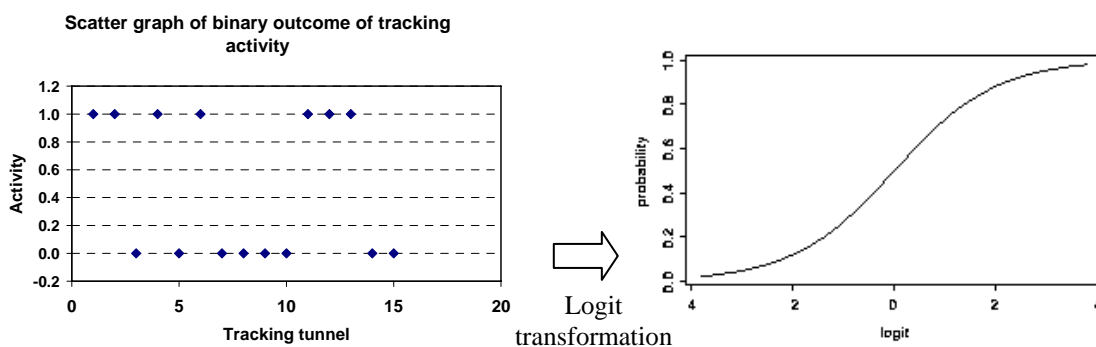
The line `"class"` is specifying which of the explanatory variables have categories ('classes') of data. `Proc genmod` then creates a 'dummy variable' for each categorical explanatory variable. Each category of a variable is compared to its dummy variable in order to ascertain the significance of the category in predicting the outcome variable.

The line `"model"` is specifying which of the explanatory variables is to be included as explanatory variables in the logistic regression model. `Tracked` is given as the outcome

variable, and "week inside onground pig_type shed_type" are included as explanatory variables in the model.

"dist=bin type3" is specifying that the output data ("tracked" activity) is binary data which is not linear, and as proc genmod is designed for linear data you need to tell the model to transform the data so it can be analysed by proc genmod. In this case the 'logit' function was used to transform the binary data to a linear outcome (Figure Appendix 4.2.1). This is done by log transforming the probability of the binary outcome using the following equation:

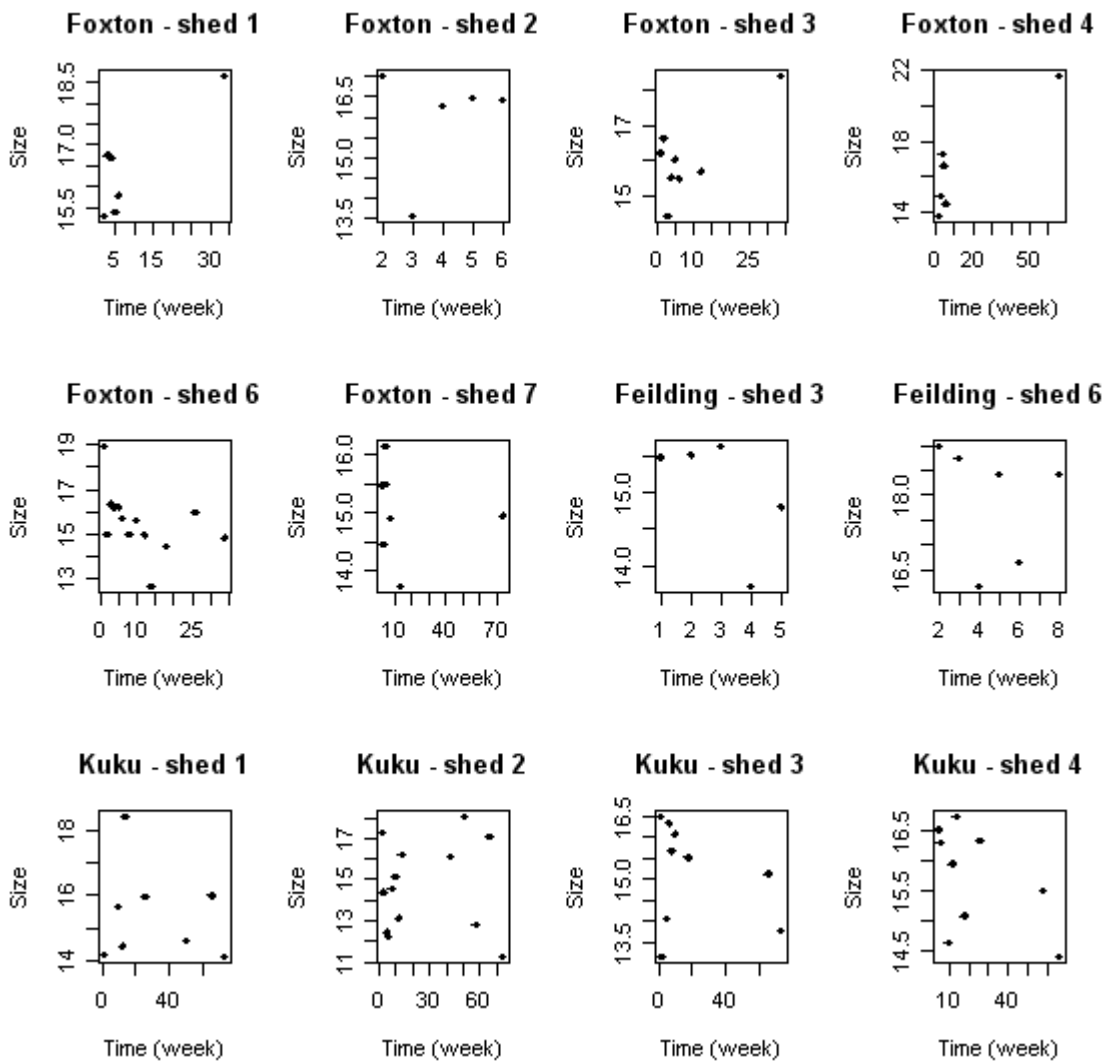
$$\text{logit}(p) = \log\left(\frac{p}{1-p}\right)$$



Appendix 4.2. Figure 1 The effect on the data of a "logit transformation", by which binary data is transformed into linear data is shown.

Proc genmod can fit models for correlated data. In this study the factors tunnel, shed and piggery are repeated each week. This is coded by the line "repeated subject=tunnel(shed piggery)". The type of correlation to be accounted for in the data is specified by "type=ar(1)".

Appendix 4.3 – Assessment of footprint size over time



Appendix 4.3. Figure 1 Scatter plots of footprint size over time for each shed with more than 5 weeks of tracking rat activity.

Appendix 4.4 – Rats collected from three piggeries

Appendix 4.4. Table 1 Specifics on rats collected from three piggeries in the Manawatu.

Farm	Date	Species	Location	Weight	Gender (M,F &J)
Piggery 1	17/12/02	Ship rat	Sh4 on window sill	195	F
Piggery 1	17/12/02	Ship rat	*	173.5	M
Piggery 1	17/12/02	Ship rat	Snap trap	157.8	F
Piggery 1	17/12/02	Ship rat	Snap trap	152.1	M
Piggery 1	17/12/02	Ship rat	DrysowSH	135.6	M
Piggery 1	17/12/02	*	DrysowSH	65.4	J
Piggery 1	18/12/02	Ship rat	*	175.6	F
Piggery 1	10/12/02	Ship rat	Poison	118.7	M
Piggery 1	10/12/02	Ship rat	Poison	127.3	M
Piggery 1	11/12/02	Ship rat	Poison	136	M
Piggery 1	11/12/02	Ship rat	Poison	130	M
Piggery 1	11/12/02	Ship rat	Poison	89	M
Piggery 1	11/12/02	Ship rat	Poison	103	M
Piggery 1	11/12/02	Ship rat	Poison	85	F
Piggery 1	12/12/02	Ship rat	Poison	192	F
Piggery 1	12/12/02	Ship rat	Poison	134	F
Piggery 1	8/12/02	Ship rat	Snap Trap	194	F
Piggery 3	12/12/2002	*	*	89.5	J
Piggery 3	12/12/2002	Norway	*	181.6	F
Piggery 3	12/12/2002	Ship rat	Sh2	125.4	M
Piggery 3	12/12/2002	*	B/n Sh1&Sh2	144.9	F
Piggery 3	12/12/2002	Norway	*	509.2	*
Piggery 3	14/11/2003	Ship rat	*	242.7	M
Piggery 3	4/02/2003	Norway	*	256	F
Piggery 3	4/02/2003	Norway	*	333.8	M
Piggery 2	18/12/2002	Norway	Behind Sh6	452.8	M
Piggery 2	18/12/2002	*	Behind Sh6	68.5	J

Piggery 2	11/12/2002	Ship rat	*	53	M
Piggery 2	12/12/2002	Norway	*	313	F
Piggery 2	22/01/2003	Norway	*	139	*

* = not recorded

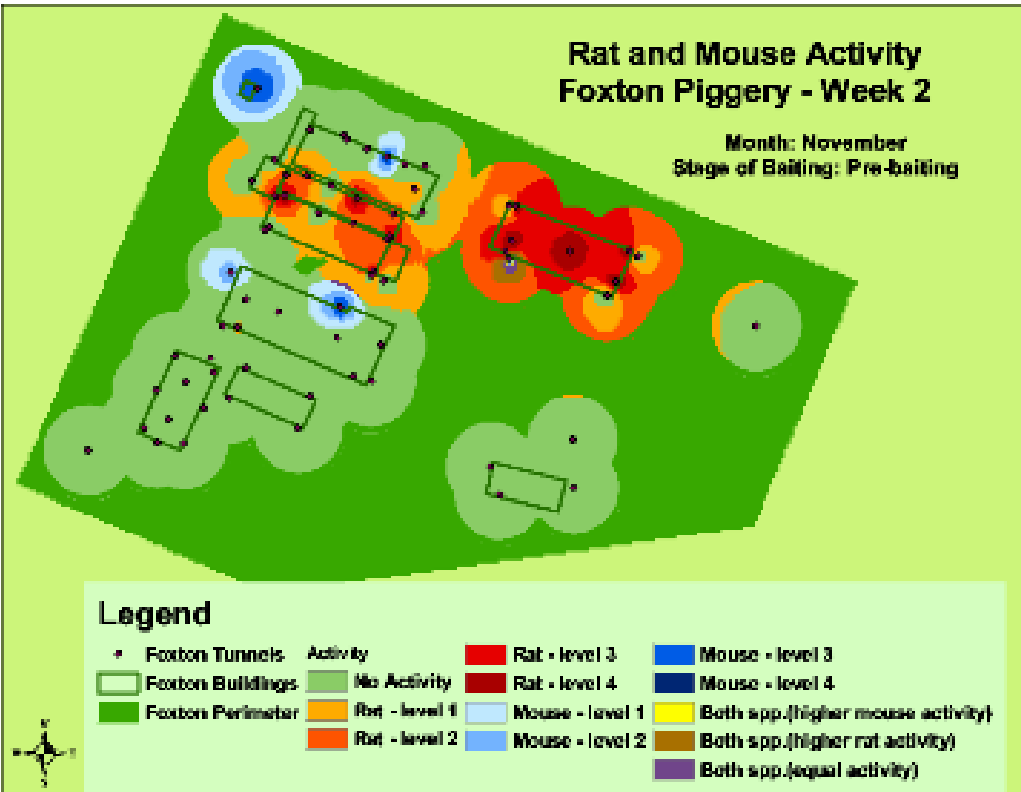
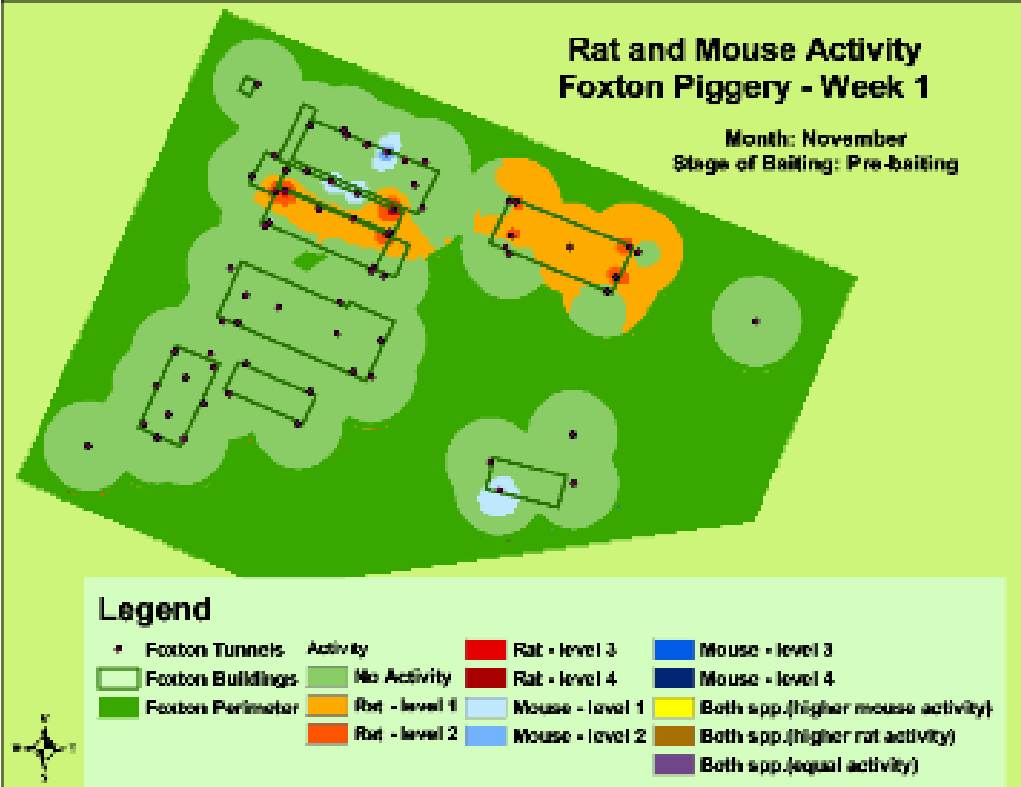
Appendix 4.5– Sequential maps showing the change in rodent distribution over time

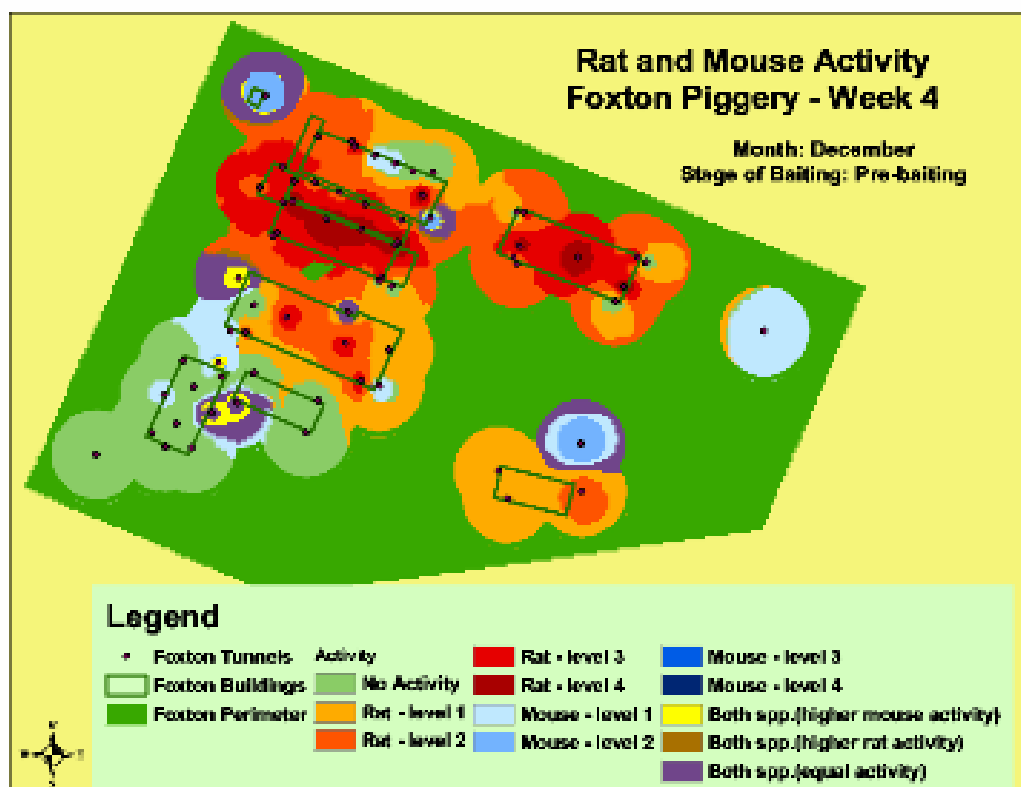
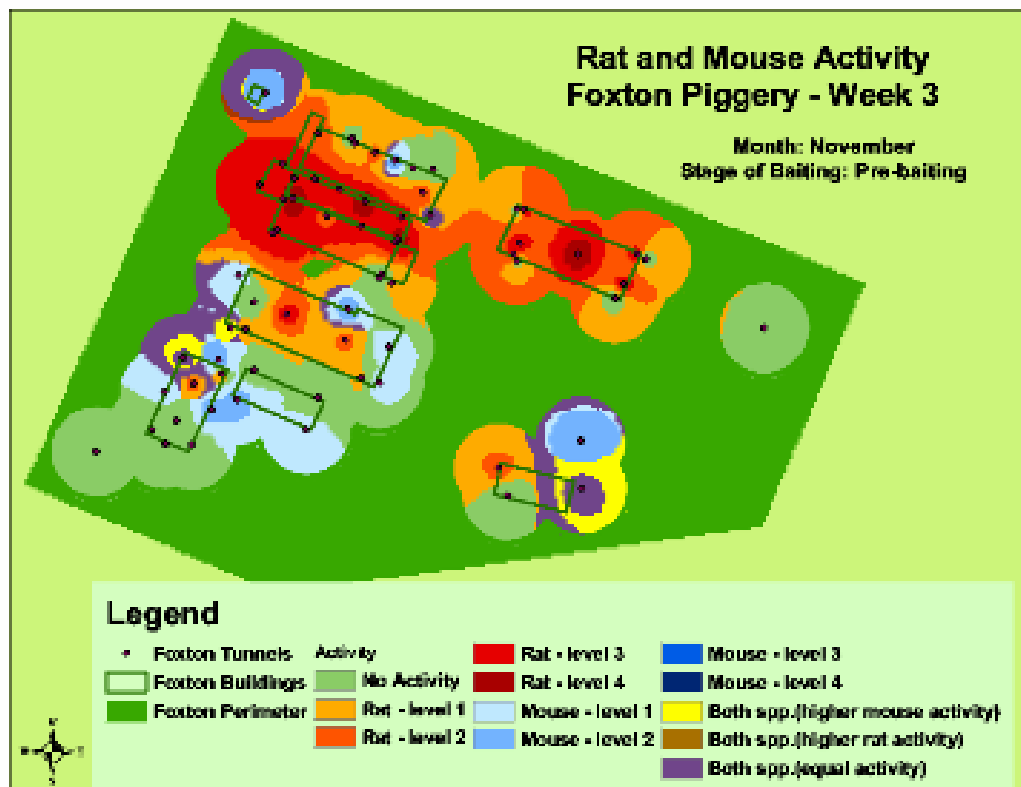
The maps in Appendix 4.5 are an aerial view of Piggeries 1 and 3. Each slide is a snapshot of monitored rodent activity for each sample night over the 74 weeks that the piggeries were studied. The maps give the perimeter of the piggery, the outline of each building, as well as the position of the monitoring tunnels and the bait stations. The title of each slide gives the week of the study the activity was monitored, followed by the month and stage of baiting at that part of the study. The back-ground colour denotes season, where green represents spring, yellow represents summer, orange represents autumn and blue represents winter. Rodent activity is shown using four levels of activity, as described in section 4.2.9. Increases in rat activity are demonstrated in red tones, and mouse activity is plotted as blue tones. Areas that were tracked by both rats and mice during the same sample night were coloured differently to illustrate the extent of species overlap in the piggery. Colours differed for whether the area showed higher mouse activity than rat activity, higher rat activity than mouse activity, or where there appeared to be equal activity by both species.

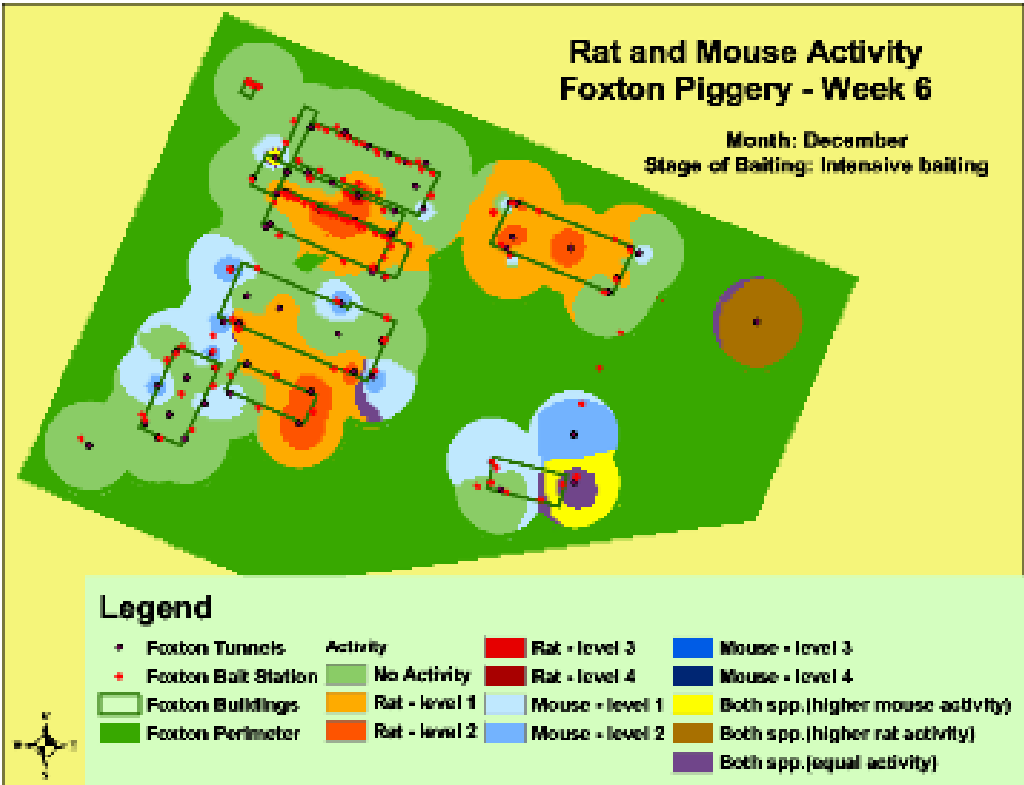
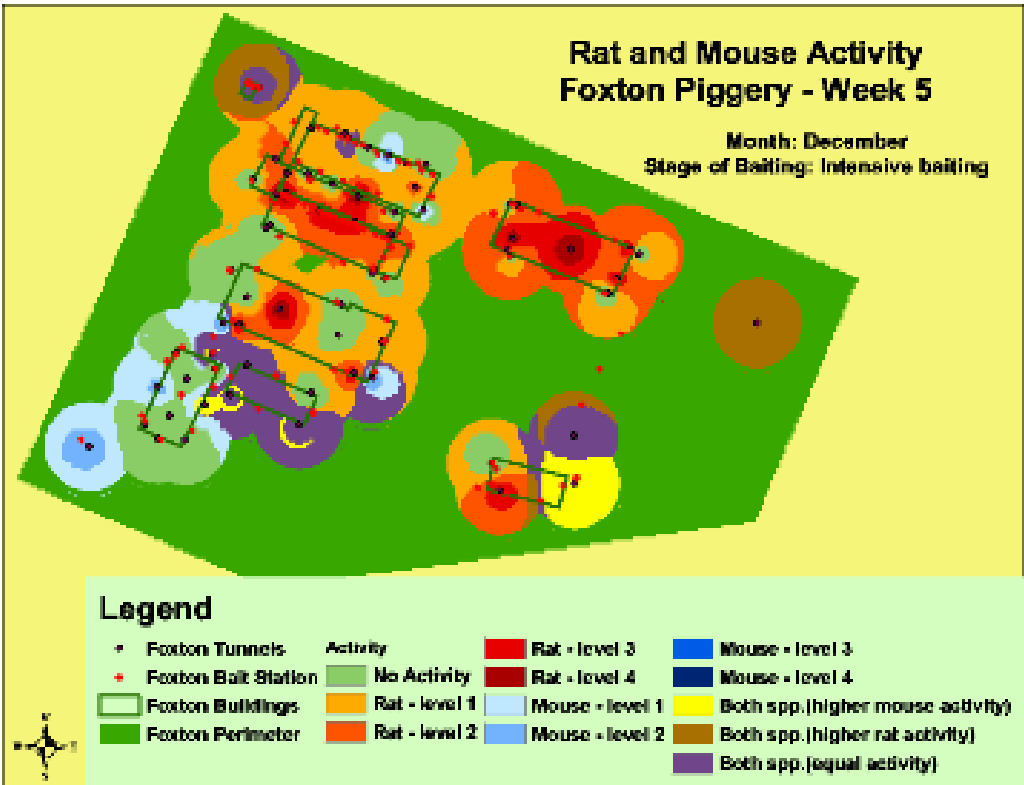
The first piggery shown is Piggery 1. This piggery (Foxton Piggery) illustrates effective rat control and an ongoing persistence in low mouse activity over the 74 weeks of the study.

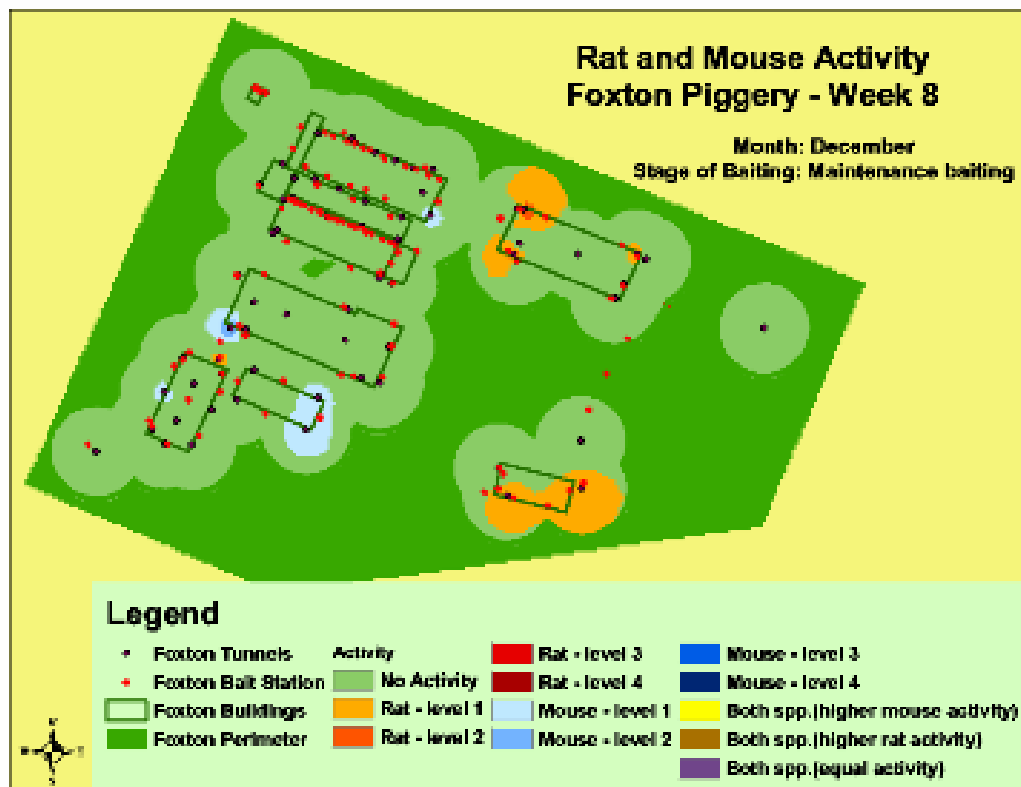
The second piggery shown is Piggery 3. This piggery (Kuku Piggery) illustrates resurgence in rat activity after a period of population reduction. This piggery also showed an ongoing persistence in mouse activity over the 74 weeks of the study, although some reduction in mouse activity throughout the farm was apparent.

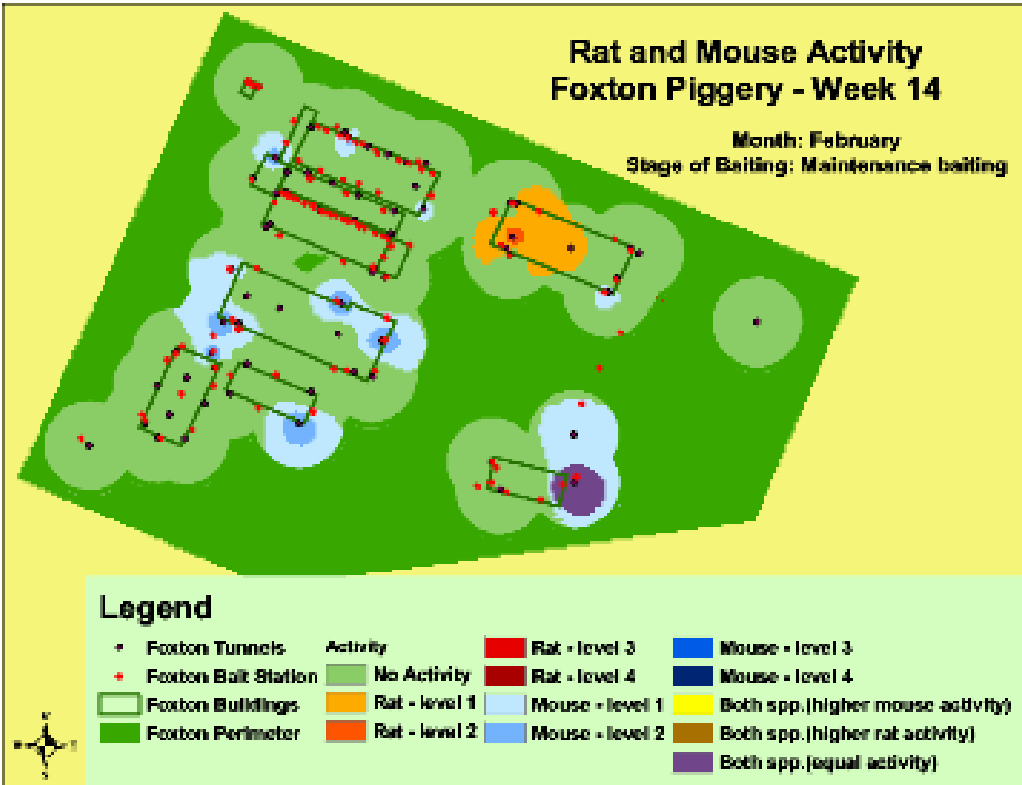
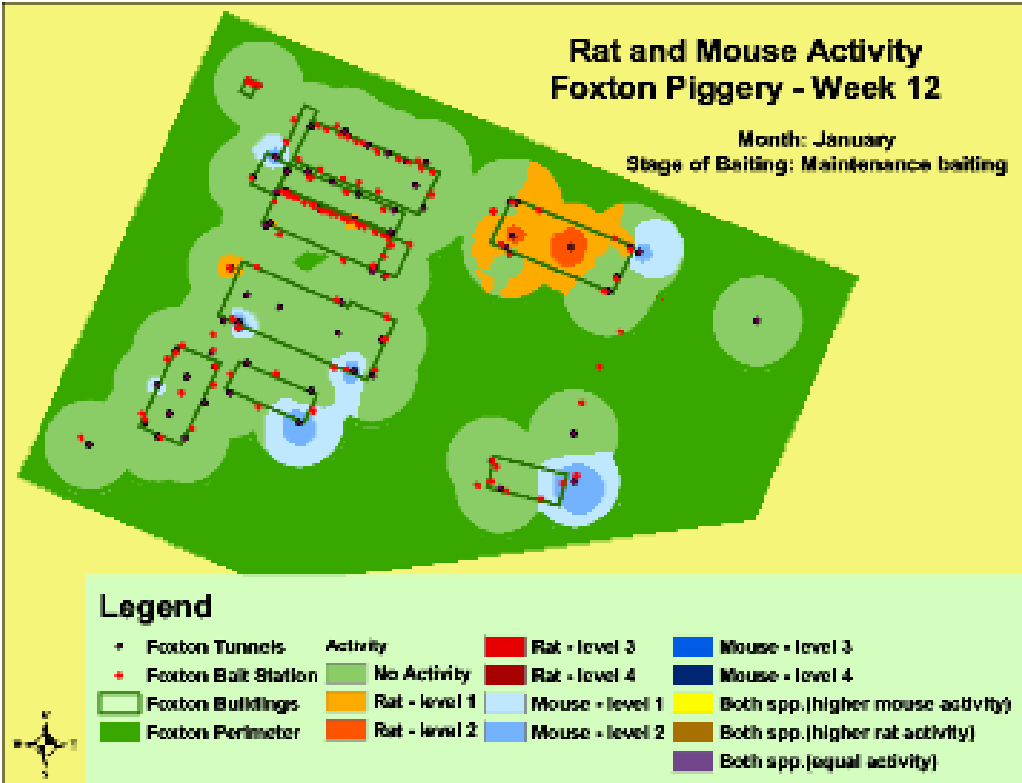
For the animated ‘movie’ of rodent activity over time for each of the three piggeries in the study please refer to the compact disk accompanying this thesis.

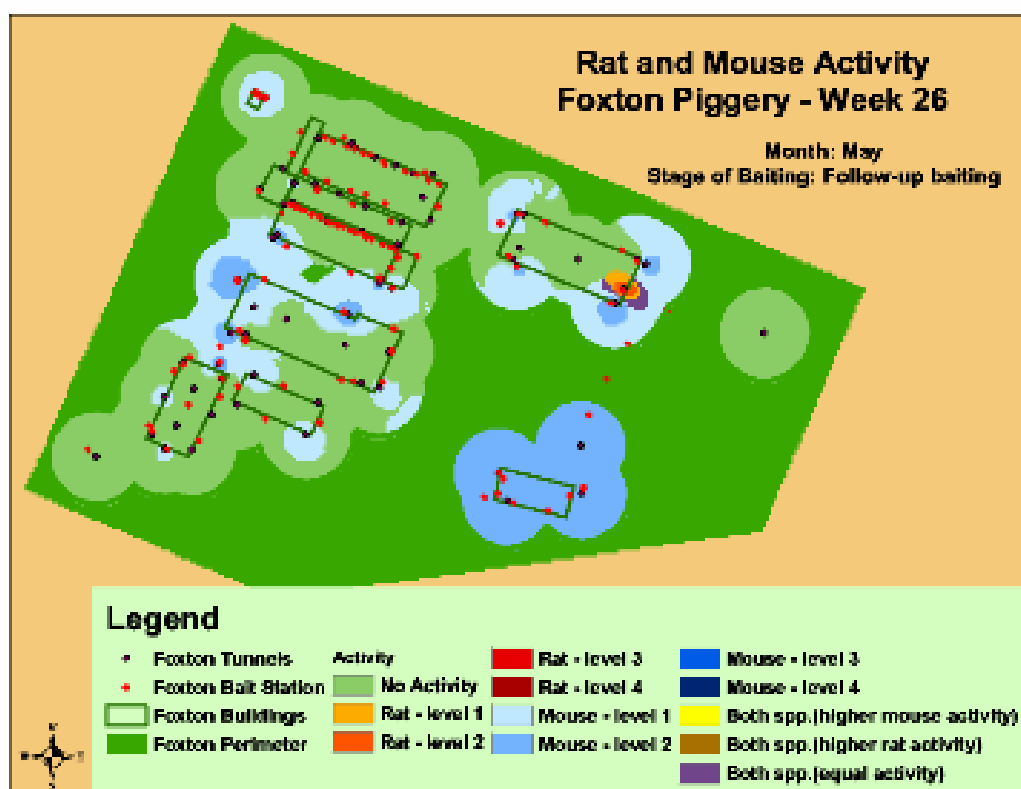
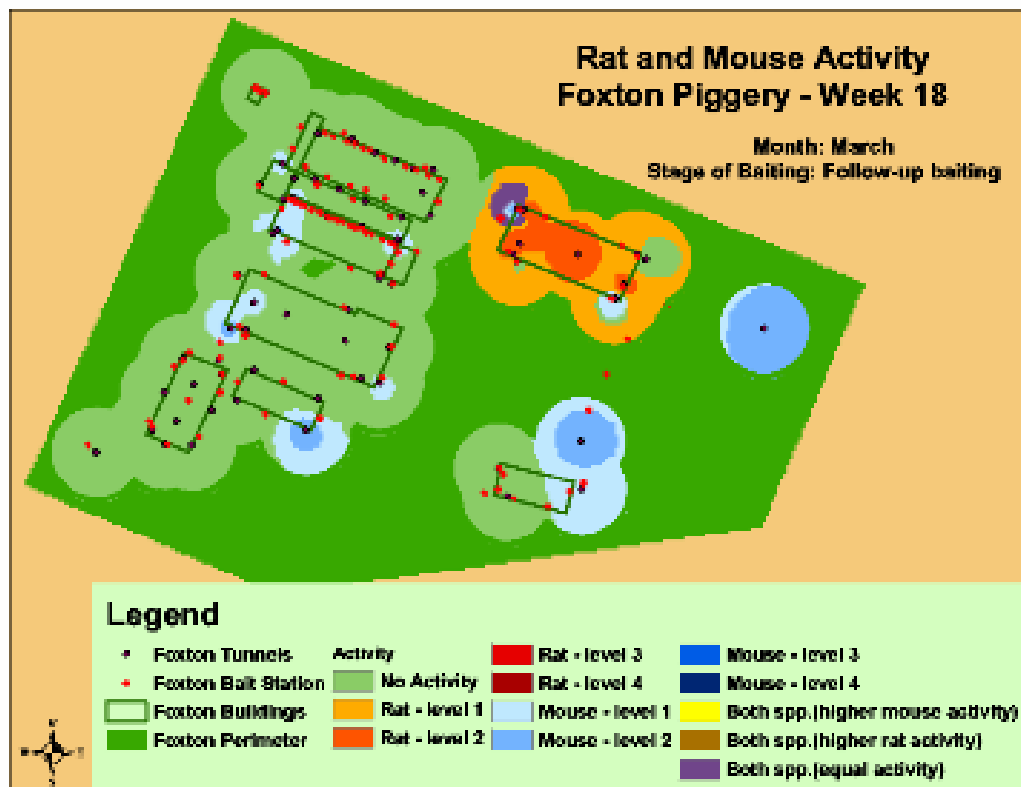


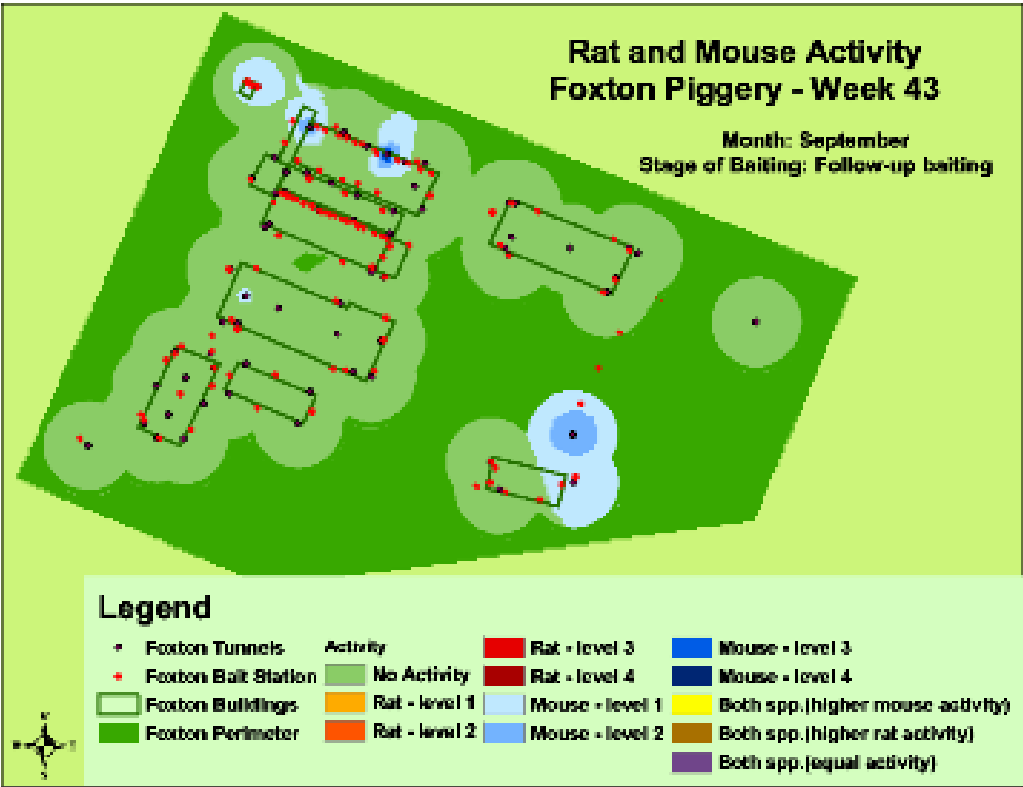
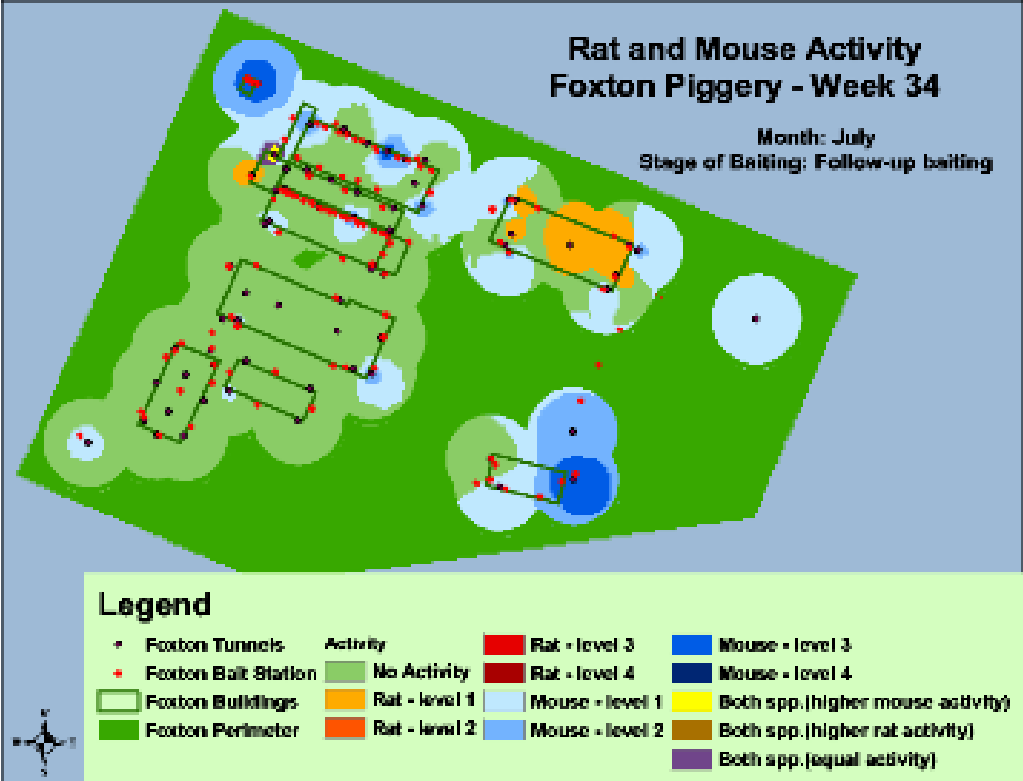


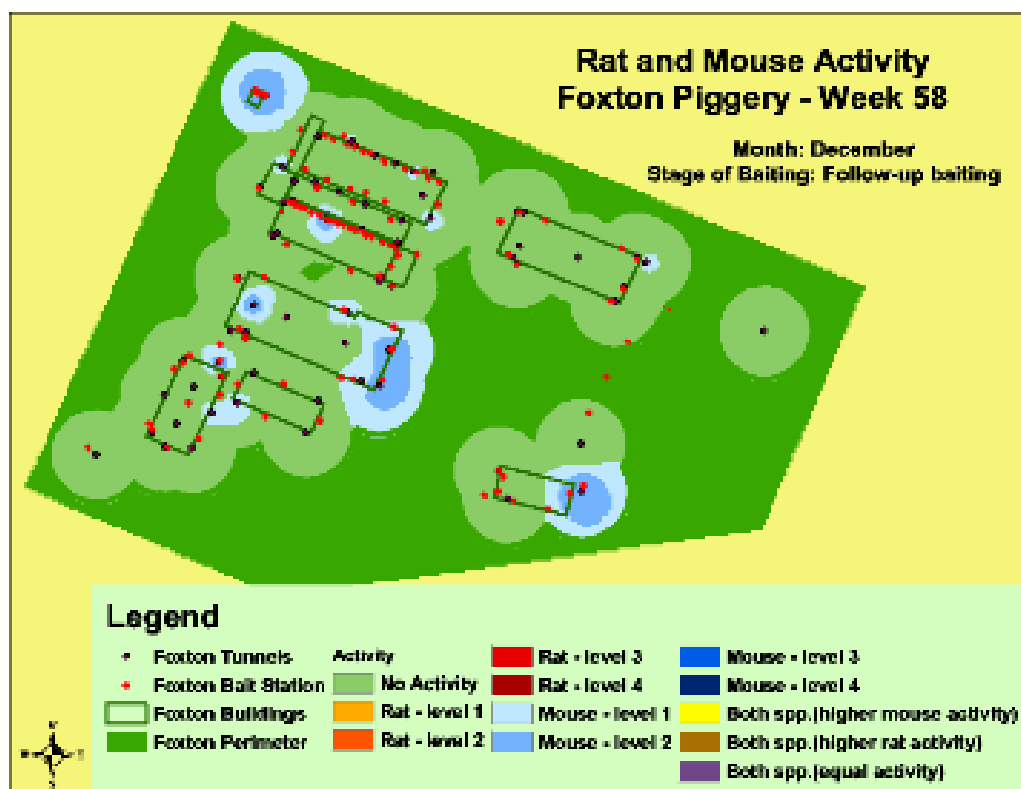
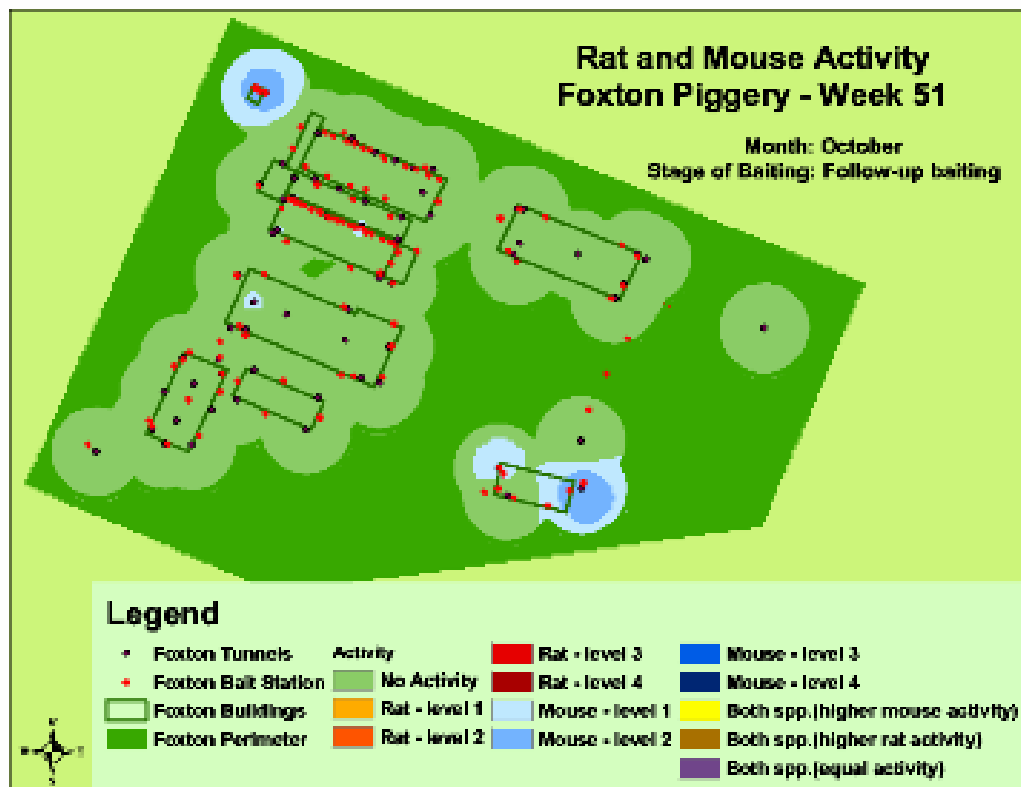


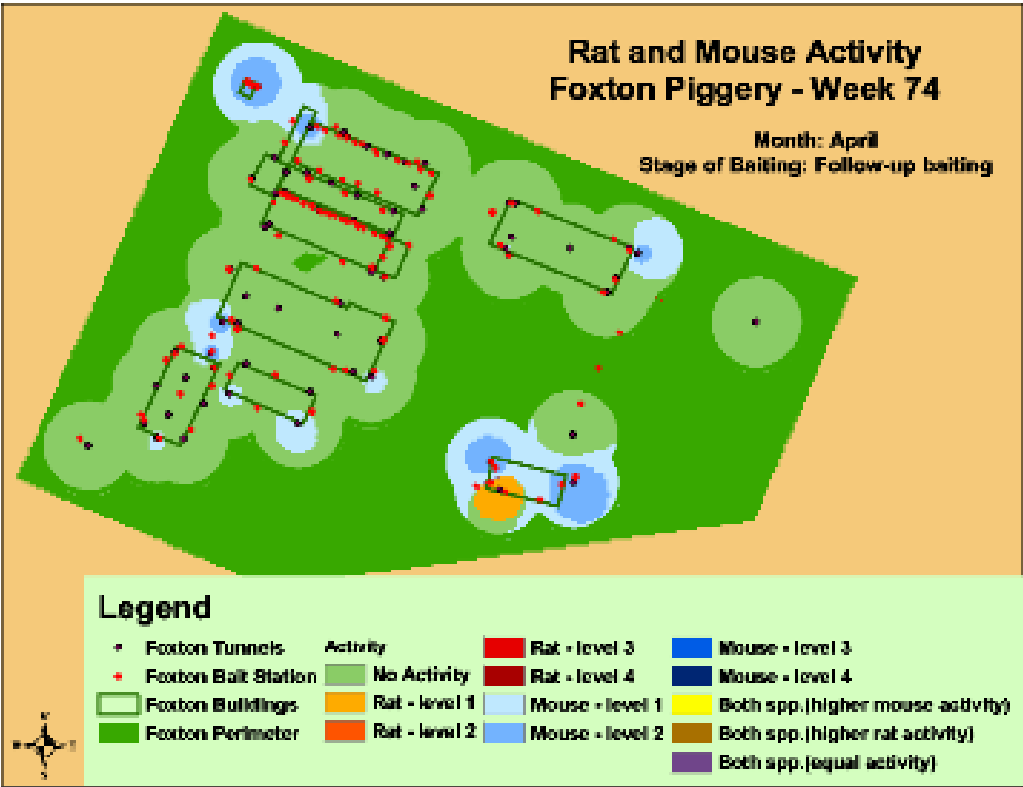
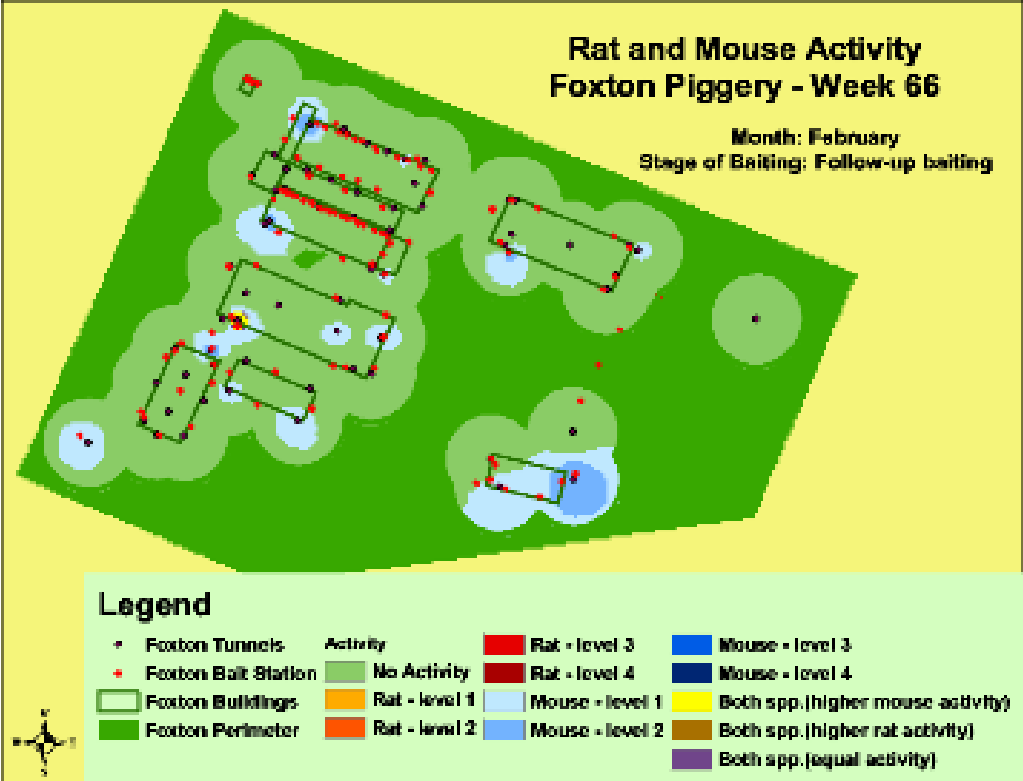


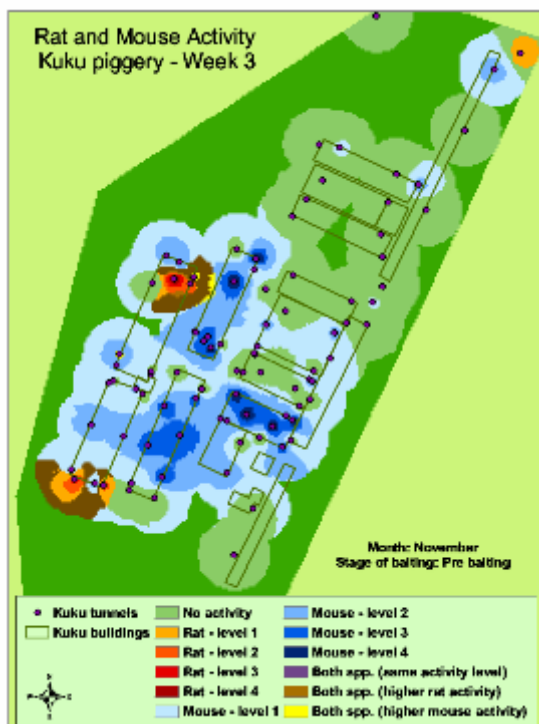




















Appendix 5.1- Input values and distributions used in the unrestricted risk assessment model

STEP Input values and distributions			
Between Herd prevalence			
R1.1	Non-confined production		=RiskPert(0,0,0.025)
R2.1	Confined production		=RiskPert(0,0,0.005)
R3.1	Backyard production		=RiskPert(0,0.002,0.05)
Within Herd prevalence			
R1.2	Non-confined production	0.4	
R2.2	Confined production	0.1	
R3.2	Backyard production		=RiskBeta(17,16)
Contribution to national production from each production system			
R4.1	Non-confined	0.01	
R4.2	Confined	0.98	
R4.3	Backyard	0.01	
Test sensitivity			
R5.1	Pepsin Digest		=RiskUniform(0.95,0.98)
R5.1	Trichinoscopy		=RiskUniform(0.92,0.95)
R5.1	No test	0	
Likelihood of surviving post mortem processes and transport			
R7	ph changes	0.99	
R8	chilling & transport	0.99	
Likelihood consumption unit has 1pg of viable <i>T. spiralis</i> larvae given that pig was infected			
R6	Offal	All herds	=RiskPert(0,0,0.005)
R6	Pork	Backyard herds	=RiskPert(0.65,0.75,0.85)
R6		Confined	=RiskPert(0,0.01,0.05)
R6		Confined and certified	=RiskPert(0,0,0.01)
Exporting countries market share of fresh/chilled product in Singapore			
L1	Offal		=0.0691/1.381
L1	Pork		=0.2779/5.557
Likelihood of ≥ 1 larvae/g of <i>T. spiralis</i> surviving preparation for consumption			
L3	Offal	0.1	
L3	Pork	0.01	
A Size of a consumption unit			
			=RiskTriang(0.05,0.1,0.2)
B Volume of fresh product consumed per capita per year			
			=C/D
	Offal (Kg)		=16*0.55
	Pork (Kg)		=26.5*0.55
C Total consumption per capita			
	Offal (Kg)		=RiskUniform(15,17)
	Pork (Kg)		=RiskUniform(25,28)
D Proportion of fresh product in diet per year			
	Offal		=RiskTriang(0,0.65,1)
	Pork		=RiskTriang(0,0.65,1)
Number of consumption units from fresh produce per year			
			=B/A
NC	Offal		=8.8/0.11667
NC	Pork		=14.58/0.1167

Appendix 5.2 – Summary structure of the Risk analysis model

Appendix 5.2. Table 1 Values, calculations and definitions for each step in the release assessment. The unit of consumption in this study was taken as a pork product. As there is a wide range in the size of any given pork product, units are stated per gram of pork product consumed.

Variable	Description	Pork
LE	The likelihood that a pig product has a larval burden of 1 larva/g or greater of viable <i>T. spiralis</i> present in a randomly selected pork product eligible for export into the Singaporean market	$LE = R4 \times R5 \times R6 \times R7$
R1	The likelihood that a pig selected from a non-confined production system is infested with <i>T. spiralis</i> .	$R1 = R1.1 \times R1.2$
R1.1	The likelihood that <i>T. spiralis</i> infection is present in a randomly selected herd with a non-confined production system, which is eligible to export to Singapore.	4.17E-03
R1.2	The likelihood that viable <i>T. spiralis</i> larvae are present at a burden of 1 larva/g or greater in a randomly selected pig from a herd that carries pigs infected with <i>T. spiralis</i> and is a non-confined production system eligible to export to Singapore.	4.00E-01
R2	The likelihood that viable <i>T. spiralis</i> larvae are present at a burden of 1 larva/g or greater in a randomly selected pig from confined herd that is eligible for export to Singapore.	$R2 = R2.1 \times R2.2$

R2.1	The likelihood that <i>T. spiralis</i> infection is present in a randomly selected herd with an confined production system that is eligible to export to Singapore.	8.33E-04
R2.2	The likelihood that viable <i>T. spiralis</i> larvae are present at a burden of 1 larva/g or greater in a randomly selected pig from a herd that carries pigs infected with <i>T. spiralis</i> and is a confined production system eligible to export to Singapore.	1.00E-01
R3	The likelihood that viable <i>T. spiralis</i> larvae are present in a randomly selected pig from a herd with a non-commercial production system that is eligible for export to Singapore.	$R3 = R3.1 \times R3.2$
R3.1	The likelihood that <i>T. spiralis</i> infection is present in a randomly selected herd with a non-commercial production system that is eligible to export to Singapore.	9.67E-03
R3.2	The likelihood that viable <i>T. spiralis</i> larvae are present at a burden of 1 larva/g or greater in a randomly selected pig from a herd that carries pigs infected with <i>T. spiralis</i> and is a non-commercial production system eligible to export to Singapore.	5.15E-01
R4	The likelihood that viable <i>T. spiralis</i> larvae are present at a burden of 1 larva/g or greater in a randomly selected pig from any farm eligible to export to Singapore.	$R4 = (R4.1 \times R1) + (R4.2 \times R2) + (R4.3 \times R3)$

R4.1	The proportion of non-confined production system herds which are eligible to export to Singapore.	$R4.1 = 1 - (R4.2 + R4.3)$
R4.2	The proportion of confined production system herds which are eligible to export to Singapore.	9.80E-01
R4.3	The proportion of non-commercial production system herds which are eligible to export to Singapore.	1.00E-02
R5	The likelihood that a viable larval burden of 1 larva/g or greater of <i>T. spiralis</i> larvae is not identified by the post mortem inspection.	$R5 = 1 - R5.1$
R5.1	The sensitivity of the post mortem test.	0.00E+00
R6	The likelihood the pork product (tissues for consumption) from an infected pig will contain a larval burden of 1 larva/g or greater of viable <i>T. spiralis</i> larvae.	0.75 ^a
R7	The likelihood that <i>T. spiralis</i> will survive post mortem pH changes.	9.90E-01
R8	The likelihood that <i>T. spiralis</i> will survive packing, storage and transportation.	9.90E-01

^aThe only value that differs between pork and offal in the release assessment is R6, where the value shown here is for pork, and the input value used for offal in the model calculations is 0.00083.

Appendix 5.2. Table 2 Values, calculations and definitions for each step in the Exposure assessment.

Variable	Description	Offal	Fresh Pork
LEE	The likelihood that a randomly selected pork product prepared for consumption in Singapore, originated from the exporting country and contains a larval burden of 1lpg or greater viable <i>T. spiralis</i> larvae.	$LEE = L1 \times L2 \times L3 \times L4$	
L1	The likelihood that a randomly selected pork product prepared for consumption had originated from the exporting country	5.00E-02	5.00E-02
L2	The likelihood that a pig from an eligible herd within the exporting country is infected with viable <i>T. spiralis</i> larvae (LE)	1.21E-07	1.09E-04
L3	The likelihood that <i>T. spiralis</i> larvae remain viable after the pork product has been prepared for human consumption	1.00E-01	1.00E-02
Annual risk of Exposure to a consumption unit infected with <i>T. spiralis</i>			
ARC	Risk to person given consumption unit	$ARC = 1 - (1 - LEE)^{NC*}$	
*NC = Number of consumption units of fresh produce per year			

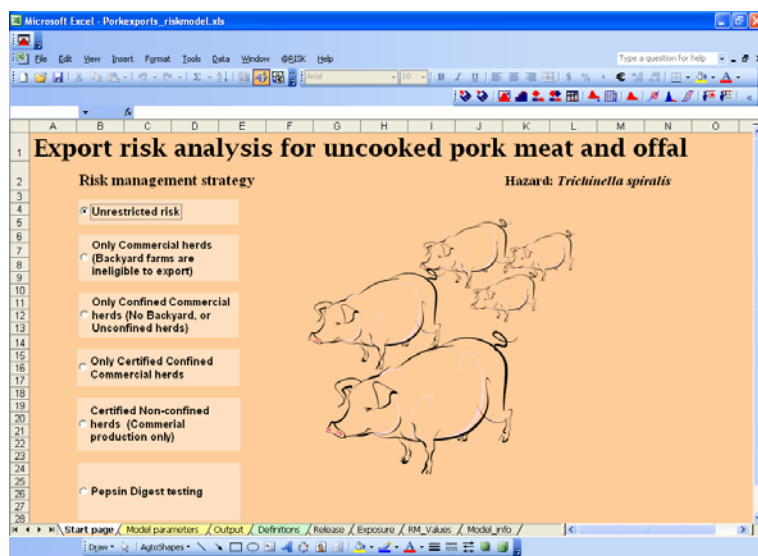
Appendix 5.3 – Descriptive results of model outputs under different situations

Appendix 5.3. Table 3 The 25th (Q1) and 75th percentiles (Q3), inter quartile range (IQR) median and range are used here to describe the distribution of the 1000 output iterations from the six different model scenarios.

	Percentiles			IQR	Median	Range
	Lower Q	Upper Q	95th			
Unrestricted	3.3E-06	1.0E-05	1.9E-05	6.8E-06	5.8E-06	4.1E-05
Excluding non-commercial	2.1E-06	7.8E-06	1.6E-05	5.7E-06	4.3E-06	4.0E-05
Confined	1.5E-08	1.1E-07	3.1E-07	9.9E-08	4.2E-08	1.1E-06
Certified confined	3.0E-10	3.6E-09	1.1E-07	3.3E-09	1.2E-09	4.3E-08
Certified non-confined	1.5E-07	7.9E-07	1.8E-06	6.4E-07	3.7E-07	4.2E-06
Pepsin digest	9.5E-08	3.0E-07	1.7E-07	2.1E-07	1.7E-07	1.4E-06

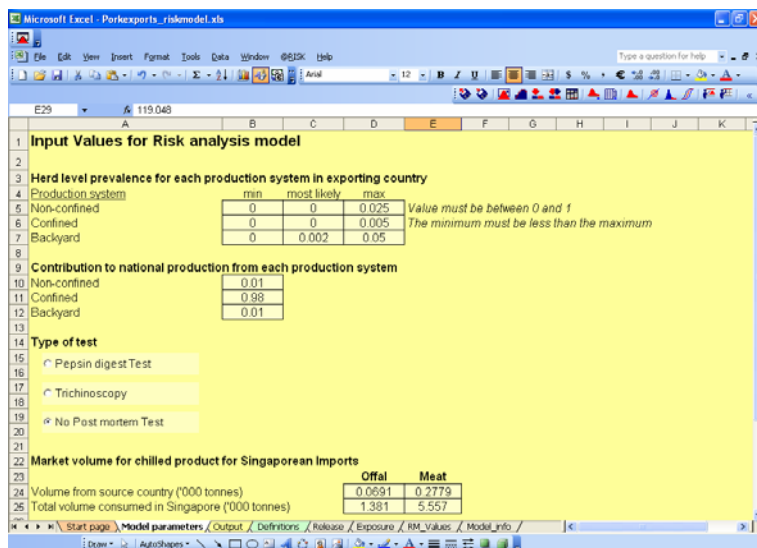
Appendix 5.4 – Appearance of quantitative risk assessment built in Excel

This appendix presents different sheets of the Excel model. The first four sheets of the model were user friendly to facilitate changes. The later sheets consisted of the model workings and contained fundamental background information that was not intended to be changed by the user. The user first selected what type of strategy they wished to assess by selecting a toggle button on the start page (see Appendix 5.4. Figure 1)



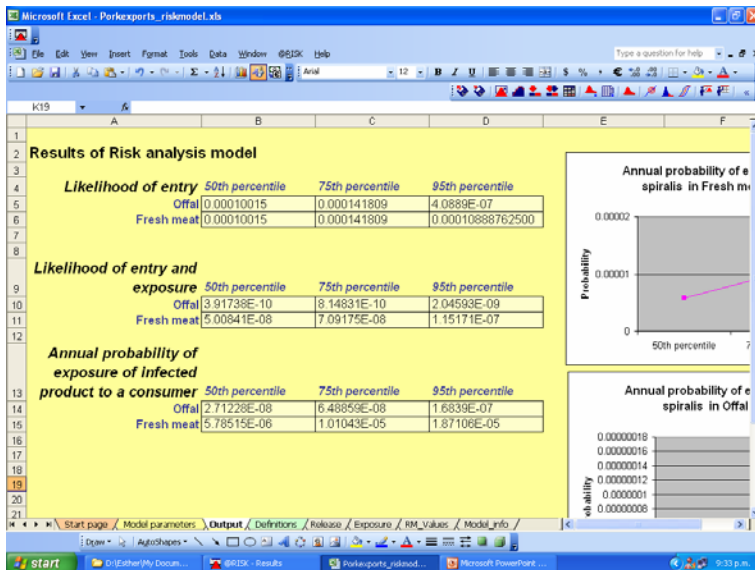
Appendix 5.4. Figure 1 Front page of model, showing the unrestricted risk selected for assessment.

The Model Parameters (see Appendix 5.4. Figure 2) are changeable by the user to allow for other data sets to be analysed in the context of the model assuming that the exports are bound for the Singapore market. This other data may be from another region or from another country interested in exporting to Singapore.



Appendix 5.4. Figure 2 Page two of the model contains changeable, market specific data.

The model results are summarised so that the user can quickly and simply see the outcome of their particular scenario. Results consisted of the risk estimates from the 50th, 75th and 95th percentiles, as calculated for the likelihood of *Trichinella spiralis* entering Singapore in New Zealand meat. Results are presented for the likelihood of both entry and also the possibility of exposure of the parasite to a consumer, and finally the results present the actual risk to an individual (see Appendix 5.4. Figure 3).



Appendix 5.4. Figure 3 The results for the unrestricted risk assessment, where pepsin digest testing is used.

A list of terms and definitions used in the model were summarised for user convenience and subject clarity (see Appendix 5.4. Figure 4).

Terms	Abbreviation	Definition
Unrestricted risk	No_Cntrl	This is the risk estimate for all pigs and pig herd types, without any risk management strategies in place
Only Commercial herds (Backyard farms are ineligible to export) (No Backyard, or Unconfined herds)	No BY	This RM allows only commercial herds to export pigs, so all pigs from backyard producers are ineligible to export
Only Certified confined herds	Conf	Both backyard and mixed production systems are ineligible to export
Certified Non-confined production systems (Commercial production only)	Conf (cert)	Only confined commercial production systems that have been approved through the certification process by an authorised person are permitted to export
Non-confined herds with Pepsin digest (all production types)	Non conf (cert)	Non-confined commercial production systems that have been approved through the certification process by an authorised person are permitted to export. Accreditation based on compliance with specific risk management strategies (All commercial production)
Non-confined production system	Non Conf (test)	Commercial piggery which does not regulate the movements and activities of its pigs, in particular of its grower herd
Confined production system		Commercial piggery which regulates the movement and activities of its pigs throughout the production stages
Backyard production system		Backyard producers, are farms producing pigs that are defined as non-commercial by the appropriate with the New Zealand Pork Industry Board
Risk management strategy	RM	This is a strategy put in place to reduce either (or both) the within herd and between herd prevalence of <i>T. spiralis</i> in pigs
Confinement		Confinement is where access to open ground and food is regulated by the stock person

Appendix 5.4. Figure 4 Definitions used in the model.

The workings of the model combine data entered into the initial pages with calculations and further data parameters from the final pages (See Appendix 5.4. Figure 5 and Appendix 5.4. Figure 6) to give the model outputs.

The screenshot shows a Microsoft Excel spreadsheet titled 'Porkeports_riskmodel.xls'. The main data area contains two tables. The first table, 'Risk management', has columns for 'No_Cntrl', 'No BY', 'Conf', 'Conf (cert)', 'Non conf (cert)', and 'Pepsin digest test'. The second table, '% reduction in herd and/or withinherd prevalence', has columns for 'No BY', 'Conf', 'Conf (cert)', 'Non conf (cert)', and 'Non Conf (test)'. The spreadsheet also includes a 'Level of infection in Pork' section with a value of 0.75.

Appendix 5.4. Figure 5 A range of values used to act on different variables to model the affects of a control method.

The screenshot shows a Microsoft Excel spreadsheet titled 'Porkeportsmodel_table.xls'. It displays a list of input parameters and their values. The parameters are grouped into sections: 'Risk management id', 'Consumption unit', 'Herd prevalence', 'Production system', 'Within Herd prevalence', 'Exporting countries market share of freshchilled product in Singapore', 'Parameters unchanged by control strategy', 'Likelihood of surviving post mortem processes and transport', 'Likelihood consumption unit has 1lpg of viable T. spiralis larvae given that pig was infected', 'Likelihood consumption unit is has 1lpg of viable T. spiralis larvae after preparation for consumption', and 'Proportion of fresh product consumed out of total product (fresh+frozen) consumption'.

Appendix 5.4. Figure 6 The input values are calculated by equations nested in the risk assessment pathways.

References

- Agri-food 2001. The Singapore Market for Red Meats - A guide for Canadian exporters (Agri-food Trade Service).
- Al-Ghamdi, A.S., 2002, Using logistic regression to estimate the influence of accident factors on accident severity. *Accident Analysis & Prevention* 34, 729-741.
- Ambrose, M. 2002. Market research report - Pork for Singapore (Singapore, Prime Consulting International Ltd.), pp. 1-17.
- Angus, S.D., 2003, Zoonoses project - Literature review. [internet source].
- Anon., 1974, *Trichinella spiralis* in New Zealand. *Surveillance* 1.
- Anon. 2001. Trichinae Certification Pilot Program (United States Department of Agriculture, National Pork Board).
- Anon., 2004a, Guide to using @RISK. Palisade Corporation.
- Anon., 2004b, Handbook on Import Risk Analysis for Animals and Animal products, Vol 2. OIE, Paris.
- Australian Government - Department of Agriculture Fisheries and Forestry 2004. Generic Import Risk Analysis (IRA) for Uncooked Pig Meat (Canberra, Biosecurity Australia).
- Ayala Bello, C., 1995. De *Trichinella spiralis* en ratos (*Rattus norvegicus*) colectadas en el Municipio de Juchitepec, Estado de Mexico. Universidad Nacional Autonoma de Mexico,
- Bell Laboratories, I. 2003. Approximate rodenticide lethal doses. In Techline (Bell Laboratories, Inc.), pp. 1-3.
- Bennett, S., Woods, T., Liyanage, W.M., Smith, D.L., 1991, A simplified general method for cluster-sample surveys of health in developing countries. *World Health Statistics Quarterly* 44, 98-106.
- Bessonv, A.S., Cuperlovic, K., Gajadhar, A.A., Gamble, H.R., van Knapen, F., Noeckler, K., Schenone, H., Zhu, X., 2003, Recommendations on the methods

- for the control of *Trichinella* in domestic and wild animals intended for human consumption. International Commission on Trichinellosis, 1-20.
- Blackwell, G.L., Potter, M.A., McLennan, J.A., 2002, Rodent density indices from tracking tunnels, snap traps and Fenn traps: do they tell the same story? *New Zealand Journal of Ecology* 26, 43-51.
- Blackwell, J.M., 1979. The role of the house mouse in disease and zoonoses. In: *Symposia of the Zoological Society of London*, London, UK, pp. 591-616.
- Boireau, P., Vallee, I., Roman, T., Perret, C., Mingyuan, L., Gamble, H.R., Gajadhar, A., 2000, *Trichinella* in horses: a low frequency infection with high human risk. *Veterinary Parasitology* 93, 309-320.
- Bolt, I., Marshall, R.B., 1995, The epidemiology of *Leptospira interrogans* serovar *pomona* in grower pig herds. *New Zealand Veterinary Journal* 43, 10-15.
- Bowman, D.D., Lynn, R.C., Eberhard, M.L., Alcaraz, A., 2003, *Georgis' Parasitology for Veterinarians*, 8th Edition. Saunders, Missouri.
- Brakes, C.R., Smith, R.H., 2005, Exposure of non-target small mammals to rodenticides: short-term effects, recovery and implications for secondary poisoning. *Journal of Applied Ecology* 42, 118-128.
- Brockie, R.E., 1977, Leptospiral infections of rodents in the North Island. *New Zealand Veterinary Journal* 25, 80-91,95-96.
- Brooks, J.D., 2000, *A-Z of food safety*. CCH New Zealand, Auckland.
- Buckle, A.P., Chia, T.H., Fenn, M.G.P., Visvalingam, M., 1997, Ranging behaviour and habitat utilisation of the Malayan wood rat (*Rattus tiomanicus*) in an oil palm plantation in Johore, Malaysia. *Crop Protection* 16, 467-473.
- Buncic, S., 1997, A case of a pig infested with *Trichinella spiralis*. *Surveillance* 24, 8.
- Cairns, G.C., 1966, The occurrence of *Trichinella spiralis* in New Zealand pigs, rats and cats. *New Zealand Veterinary Journal* 14, 84-88.
- Calhoun, J.B., 1963, *The ecology and sociology of the Norway rat*. United States Department of Health, Education and Welfare, Public Health Service Publication 1008.

- Carter, M.E., Cordes, D.O., 1980, Leptospirosis and other infections of *Rattus rattus* and *Rattus norvegicus*. New Zealand Veterinary journal 28, 45-50.
- Cassens, R.G., 1966, General aspects of postmortem changes, In: Briskey, E.J., Cassens, R.G., Trautman, J.C. (Eds.) The Physiology and Biochemistry of Muscle as a Food. The University of Wisconsin Press, Madison.
- Christley, R.M., Rose, R.J., Hodgson, D.R., Reid, S.W.J., Evans, S., Bailey, C., Hodgson, J.L., 2000, Issues associated with the application to veterinarians of a mailed questionnaire regarding lower respiratory-tract disease in racehorses. Preventive Veterinary Medicine 46, 161-170.
- Clear, M., Morris, S., 2004, *Trichinella spiralis* monitoring in pigs and horses. Surveillance 31, 3-5.
- Coralde, F. 2003. Waste Management Engineer (Palmerston North).
- Cork, S.C., Marshall, R.B., Madie, P., Fenwick, S.G., 1995, The role of wild birds and the environment in the epidemiology of Yersinia in New Zealand. New Zealand Veterinary Journal 43, 169-174.
- Corrigan, R.M., 2001, Rodent IPM for Livestock Facilities, In: Moreland, D. (Ed.) Rodent Control: A practical guide for pest management professionals. Pest Control Technology, pp. 295-343.
- Corwin, C., 1999, Internal Parasites, In: Straw, B.E. (Ed.) Diseases of swine. Iowa State University Press, Iowa, pp. 719-721.
- Cowan, D., Dunsford, G., Gill, E., Jones, A., Kerins, G., MacNicoll, A., Quy, R., 1995, The impact of resistance on the use of second-generation anticoagulants against rats on farms in southern England. Pesticide Science 43, 83-93.
- Davies, P.R., Morrow, W.E.M., Deen, J., Gamble, H.R., Patton, S., 1998, Seroprevalence of *Toxoplasma gondii* and *Trichinella spiralis* in finishing swine raised in different production systems in North Carolina, USA. Preventive Veterinary Medicine 36, 67-76.
- Dickman, C.R., 2003. Management of mammalian pests: The problem of indirect interactions between species. In: 3rd International Wildlife Management Conference, Christchurch.

- Duplantler, J.M., Rakotondravony, D., 1999, The rodent problem in Madagascar: agricultural pest and threat to human health. Ecologically-based management of rodent pests, 441-459.
- Dupouy-Camet, J., 2000, Trichinosis: a worldwide zoonosis. *Veterinary Parasitology* 93, 191-200.
- Elliot, D.C., 1960, A search for infections of *Trichinella spiralis* in New Zealand pigs. *The New Zealand Veterinary Journal* 8, 28.
- Endepols, S., Klemann, N., Pelz, H.-J., Ziebell, K.-L., 2003, A scheme for the placement of rodenticide baits for rat eradication on confinement livestock farms. *Preventive Veterinary Medicine* 58, 115-123.
- Enemark, H.L., Bjorn, H., Henriksen, S.A., Nielsen, B., 2000, Screening for infection of *Trichinella* in red fox (*Vulpes vulpes*) in Denmark. *Veterinary Parasitology* 88, 229-237.
- European-Commission 2001. Trichinellosis, epidemiology, methods of detection and *Trichinella* - free pig production. In Health and consumer protection directorate-general, Health, S.c.o.V.M.r.t.P., ed.
- Feidt, C., Brun-Bellut, J., 1999, Release of major ions during rigor mortis development in kid *Longissimus dorsi* muscle. *Meat Science* 51, 81-90.
- Fitzgerald, B.M., Karl, B.J., Moller, H., 1981, Spatial organization and ecology of a sparse population of house mice (*Mus musculus*) in a New Zealand forest. *Journal of Animal Ecology* 50, 489-518.
- Foegeding, P.M., 1997, Driving predictive modelling on a risk assessment path for enhanced food safety. *International Journal of Food Microbiology* 36, 97-95.
- Forbes, L.B., Gajadhar, A.A., 1999, A validated *Trichinella* digestion assay and an associated sampling and quality assurance system for use in testing pork and horse meat. *Journal of Food Protection* 62, 1308-1313.
- Fotheringham, S., Rogerson, P., 1994, *Spatial Analysis and GIS*. Taylor & Francis Ltd, Buffalo, 1-281 pp.

- Fraser, K.W., Overton, J.M., Warburton, B., Rutledge, D.T. 2003. Predicting spatial patterns of animal pest abundance: a case study of the brushtail possum (*Trichosurus vulpecula*). In Science for Conservation, pp. 1-57.
- Frydas, S.I., Alexakias, A.E., van Knapen, F., 1995, Prevalence of IgG antibodies to *Trichinella spiralis* in dogs in Macedonia, Northern Greece. Veterinary Parasitology 59, 81-85.
- Gajadhar, A., Bisailon, J., Appleyard, G.D., 1997, Status of *Trichinella spiralis* in domestic swine and wild boar in Canada. Canadian Journal of Veterinary Research, 256-259.
- Gajadhar, A.A., Forbes, L.B., 2002, An internationally recognized quality assurance system for diagnostic parasitology in animal health and food safety, with example data on trichinellosis. Veterinary Parasitology 103, 133-140.
- Gajadhar, A.A., Gamble, H.R., 2000, Historical perspectives and current global challenges of *Trichinella* and trichinellosis. Veterinary Parasitology 93, 183-189.
- Gamble, H.R., 1999, Factors affecting the efficiency of pooled sample digestion for the recovery of *Trichinella spiralis* from muscle tissue. International Journal of Food Microbiology 48, 73-78.
- Gamble, H.R., Bessonov, A.S., Cuperlovic, K., Gajadhar, A.A., van Knapen, F., Noeckler, K., Schenone, H., Zhu, X., 2000, International Commission on Trichinellosis: Recommendations on methods for the control of *Trichinella* in domestic and wild animals intended for human consumption. Veterinary Parasitology 93, 393-408.
- Gamble, H.R., Brady, R.C., Bulaga, L.L., Berthoud, C.L., Smith, W.G., Detweiler, L.A., Miller, L.E., Lautner, E.A., 1999, Prevalence and risk association for *Trichinella* infection in domestic pigs in the northeastern United States. Veterinary Parasitology 82, 59-69.
- Gamble, H.R., Bush, E., 1999, Sereoprevalence of *Trichinella* infection in domestic swine based on the national animal health monitoring system's 1990 and 1995 swine surveys. Veterinary Parasitology 80, 303-310.

- Geddes, Grosset, 2003, English Dictionary and Thesaurus. David Dale House, New Lanark.
- Gill, J., 1995, Rats in New Zealand as carriers of disease. *Surveillance* 22, 15-16.
- Gilles, C., Williams, D. 2000. Using tracking tunnels to monitor rodents and other small mammals (Wellington, Department of Conservation), pp. 1-14.
- Gottstein, B., Pozio, E., Connolly, B., Gamble, H.R., Eckert, J., Jakob, H.-P., 1997, Epidemiological investigation of trichinellosis in Switzerland. *Veterinary Parasitology* 72, 201-207.
- Gregory, N.G., 1999, Survey of sow accommodation systems used in New Zealand. *New Zealand Journal of Agricultural Research* 42, 187-194.
- Hartnett, E.K., L.; Newell, D.; Wooldridge, M.; Gettinby, G., 2001, A quantitative risk assessment for the occurrence of campylobacter in chickens at the point of slaughter, Vol 127. Cambridge University Press, 195-206 pp.
- Heiberg, A., Leirs, H., Siegismund, H.R., 2003, Bromadiolone resistance does not respond to absence of anticoagulants in experimental population of Norway rats, In: Singleton, G.R., Hinds, L.A., Krebs, C.J., Spratt, D.M. (Eds.) *Rats, mice and people: rodent biology and management*. Australian Centre for International Agricultural Research, Canberra, pp. 461-464.
- Henriksen, S.A., 1978, Recovery of *Trichinella spiralis* larvae from frozen muscle samples. *Acta Veterinaria Scandinavica* 19, 607-608.
- Hoberg, E., Aubry, K., Brittell, J., 1990, Helminth parasitism in martens (*Martes americana*) and ermines (*Mustela erminea*) from Washington, with comments on the distribution of *Trichinella spiralis*. *J Wildl Dis* 26, 447-452.
- Hosmer, D.W., Lemeshow, S., 2000, *Applied Logistic Regression*, 2nd Edition. John Wiley & Sons, Inc., 373 p.
- Hurnikova, Z., Snabel, V., Pozio, E., Reiterova, K., Hrcikova, G., Halasova, D., Dubinsky, P., 2005, First record of *Trichinella pseudospiralis* in the Slovak Republic found in domestic focus. *Veterinary Parasitology* 128, 91-98.
- Inglis, I.R., Shepherd, D.S., Smith, P., Haynes, P.J., Bull, D.S., Cowan, D.P., Whitehead, D., 1996, Foraging behaviour of wild rats (*Rattus norvegicus*)

- towards new foods and bait containers. *Applied Animal Behaviour Science* 47, 175-190.
- Innes, J., Brown, K., Jansen, P., Shorten, R., Williams, D., 1996, Kokako population studies at Rotoehu Forest and on Little Barrier Island. Department of Conservation, Wellington.
- Innes, J., Warburton, B., Williams, D., Speed, H., Bradfield, P., 1995, Large-scale poisoning of ship rats (*Rattus rattus*) in indigenous forests of the North Island, New Zealand. *New Zealand Journal of Ecology* 19, 5-17.
- Innes, J.G., 1990, Ship Rat, In: King, C.M. (Ed.) *The handbook of New Zealand mammals*. Oxford University Press New Zealand, Auckland, pp. 206-224.
- Innes, J.G., King, C.M., Flux, M., Kimberley, M.O., 2001, Population biology of the ship rat and Norway rat in Pureora Forest Park, 1983-87. *New Zealand Journal of Zoology* 28, 57-78.
- James, R.E., Clout, M.N., 1996, Nesting success of New Zealand Pigeons (*Hemiphaga Novaeseelandiae*) in response to a rat (*Rattus rattus*) poisoning programme at Wenderholm Regional Park. *New Zealand Journal of Ecology* 20.
- Jones, R.D.K., L.; England, T.; MacMillan, A.; Wooldridge, M., 2004, A quantitative assessment for the importation of brucellosis-infected cattle into Great Britain from selected European countries. *Preventive Veterinary Medicine* 63, 51-61.
- Joshi, D.D., Moller, L.N., Maharjan, M., Kapel, C.M.O., 2005, Serological evidence of Trichinellosis in local pigs of Nepal. *Veterinary Parasitology* 132, 155-157.
- Jovic, S., Djordjevic, M., Pavlovic, S., Radenkovic, B., 2001, Infectivity of *Trichinella spiralis* in pork buried in the ground. *Parasite* 8 (2 Suppl), S213-215.
- Julian, A., 2002, *Trichinella spiralis* in New Zealand. *FSB News*, 4-5.
- Kapel, C.M.O., 2000, Host diversity and biological characteristics of the *Trichinella* genotypes and their effect on transmission. *Veterinary Parasitology* 93, 263-278.
- Kapel, C.M.O., 2005, Changes in the EU legislation on *Trichinella* inspection - New challenges in the epidemiology. *Veterinary Parasitology* 132, 189-194.
- Kapel, C.M.O., Webster, J.P., Lind, P., Pozio, E., Henriksen, S.A., Murrell, K.D., Nansen, P., 1998, *Trichinella spiralis*, *T. britovi*, and *T. navita*: Infectivity,

- larval distribution in muscle, and antibody response after experimental infection of pigs. *Parasitology research*, 264-271.
- Kassai, T., 1999, *Veterinary Helminthology*. Reed Educational and Professional Publishing Ltd, Budapest, 133-136 pp.
- Kiang, Y.P. 1998. Trends in Food Consumption. In *Statistics Singapore Newsletter* (Singapore, Singapore Department of Statistics).
- Kijlstra, A., Eissen, O.A., Cornelissen, J., Munniksmma, K., Eijck, I., Kortbeek, T., 2004, *Toxoplasma gondii* infection in animal-friendly pig production systems. *IVOS* 45, 3165-3169.
- King, C.M., 1990a, *The handbook of New Zealand mammals*. Oxford University Press New Zealand, Auckland.
- King, C.M., 1990b, Stoat, In: King, C.M. (Ed.) *The handbook of New Zealand mammals*. Oxford University Press, Auckland, pp. 288-312.
- King, C.M., Edger, R.L., 1977, Techniques for trapping and tracking stoats (*Mustela erminea*); a review, and a new system. *New Zealand Journal of Zoology* 4, 193-212.
- Kociecka, W., Boczon, K., Pozio, E., van Knapen, F., 2003, *Trichinella*, In: Miliotis, M.D., Bier, J.W. (Eds.) *International Handbook of Foodborne Pathogens*. Marcel Dekker, Inc., New York, pp. 637-658.
- Lammerding, A.M., Fazil, A., 2000, Hazard identification and exposure assessment for microbial food safety risk assessment. *International Journal of Food Microbiology* 58, 147-157.
- Langton, S.D., Cowan, D.P., Meyer, A.N., 2001, The occurrence of commensal rodents in dwellings as revealed by the 1996 English House Condition Survey. *Journal of Applied Ecology* 38, 699-709.
- Lawson, A.B., Zhou, H., 2005, Spatial statistical modeling of disease outbreaks with particular reference to the UK foot and mouth disease (FMD) epidemic of 2001. *Preventive Veterinary Medicine* 71, 141-156.

- Le Moine, V., Vannier, P., Jestin, A., 1987, Microbiological studies of wild rodents in farms as carriers of pig infectious agents. *Preventive Veterinary Medicine* 4, 399-408.
- Leiby, D.A., Duffy, C.H., Murrell, K.D., Schad, G.A., 1990, *Trichinella spiralis* in an agricultural ecosystem: Transmission in the rat population. *Journal of Parasitology* 76, 360-364.
- Leung, L.K.-P., Clark, N.M., 2005, Bait avoidance and habitat use by the roof rat, *Rattus rattus*, in a piggery. *International Biodeterioration & Biodegradation* 55, 77-84.
- Liberona, H.E., MacDiarmid, S.C., 1988, *Trichinella spiralis* in New Zealand. *Surveillance* 15, 17-18.
- Liu, M., Boireau, P., 2002, Trichinellosis in China: epidemiology. *TRENDS in Parasitology* 18, 553-556.
- Lo Fo Wong, D.M., Dahl, J., Wingstrand, A., van der Wolf, P.J., von Altrock, A., Thorberg, B.M., 2004, A European longitudinal study in Salmonella seronegative- and seropositive-classified finishing pig herds. *Epidemiology and Infection* 132, 903-914.
- Long, J.L., 2003, *Introduced mammals of the world: their history, distribution and influence*. CSIRO Publishing, Collingood.
- Malakauskas, A., 2002. *Molecular Epidemiology of Trichinellosis in Lithuania and biological Characteristics of Trichinella genotypes in Rat*. Ph.D. Thesis. The Royal Veterinary and Agricultural University, Copenhagen, Denmark.
- Malakauskas, A., Kapel, C.M.O., Webster, P., 2001, Infectivity, persistence, and serological response of nine *Trichinella* genotypes in rats. *Parasite* 8, 216-222.
- Marino, M.R., Brown, T.J., Waddington, D.C., Brockie, R.E., Kelly, P.J., 1992, *Giardia intestinalis* in North Island possums, house mice and ship rats. *New Zealand Veterinary Journal* 40, 24-27.
- Mason, P.C., 1978, *Trichinella spiralis* in New Zealand. *New Zealand Veterinary Journal*, 215.

- McDermott, J.J., Schukken, Y.H., 1994, A review of methods used to adjust for cluster effects in explanatory epidemiological studies of animal populations. *Preventive Veterinary Medicine* 18, 155-173.
- Moors, P.J., 1990, Norway Rat, In: King, C.M. (Ed.) *The Handbook of New Zealand Mammals*. Oxford University Press, Auckland, pp. 193-206.
- Murphy, E.C., Pickard, C.R., 1990, House Mouse, In: King, C.M. (Ed.) *The handbook of New Zealand Mammals*. Oxford University Press New Zealand, Auckland, pp. 225-245.
- Murray, N., 2004, *OIE Handbook on Import Risk Analysis for animals and Animal Products, Vol 1*. World organisation for animal health, France.
- Murrell, K.D., Pozio, E., 2000, Trichinellosis: the zoonosis that won't go quietly. *International Journal for Parasitology* 30, 1339-1349.
- Murrell, K.D., Stringfellow, F., Dame, J.B., Leiby, D.A., Duffy, C., Schad, G.A., 1987, *Trichinella spiralis* in an agricultural ecosystem. II. Evidence for natural transmission of *Trichinella spiralis* from domestic swine to wildlife. *Journal of Parasitology* 73, 103 - 109.
- New Zealand Pork Industry Board 2003. *The NZPIB's export vision: Pork of New Zealand*.
- New Zealand Pork Industry Board 2004. *Pork production in New Zealand: Information for potential producers and investors in the pork industry*.
- New Zealand Veterinary Association, 2004, *Trichinella* confirmed in a horse in the North Island of New Zealand. *FSB News*, 7.
- Nockler, K., Pozio, E., Voigt, W.P., Heidrich, J., 2000, Detection of *Trichinella* infection in food animals. *Veterinary Parasitology* 93, 335-350.
- NZPIB 2003. *The NZPIB's export vision: Pork of New Zealand*.
- NZPIB 2004. *Pork production in New Zealand: Information for potential producers and investors in the pork industry*.
- NZVA, 2004, *Trichinella* confirmed in a horse in the North Island of New Zealand. *FSB News*, 7.

- Obendorf, D.L., 1990, *Trichinella pseudospiralis* infection in Tasmanian wildlife. Australian Veterinary Journal 67, 108-110.
- O'Connor, C.E., Eason, C.T., 2000, Rodent baits and delivery systems for island protection. Department of Conservation, Wellington.
- Oivanen, L., Mikkonen, T., Haltia, L., Karhula, H., Saloniemi, H., Sukura, A., 2002, Persistence of *Trichinella spiralis* in rat carcasses experimentally mixed in different feed. Acta Veterinaria Scandinavica 43, 203-210.
- Oivanen, L., Nareaho, A., Jokela, S., Rikula, U., Gamble, R., Sukura, A., 2005, The prevalence of *Trichinella* infection in domestic dogs in Finland. Veterinary Parasitology 132, 125-129.
- Ortga-Pierres, M.G., Arriaga, C., Yopez-Mulia, L., 2000, Epidemiology of trichinellosis in Mexico, Central and South America. Veterinary Parasitology 93, 201-225.
- Otte, M.J., Gumm, I.D., 1997, Intra-cluster correlation coefficients of 20 infections calculated from the results of cluster-sample surveys. Preventive Veterinary Medicine 31, 147-150.
- Palisade Corporation 2005. @RISK (USA).
- Panageas, K.S., Schrag, D., Riedel, E., Bach, P.B., Begg, C.B., 2003, The effect of clustering of outcomes on the association of procedure volume and surgical outcomes. Annals of Internal Medicine 139, 658-665.
- Paterson, K., Black, A., Reichel, M.P., 1997, Porcine trichinosis diagnosed in the Rotorua area. Surveillance 24, 6-8.
- Pelz, H.J., Klemann, N., 2004, Rat control strategies in organic pig and poultry production with special reference to rodenticide resistance and feeding behaviour. NJAS- Wageningen journal of Life Sciences 52, 173-184.
- Pozio, E., 1998, Trichinellosis in the European Union: Epidemiology, Ecology and Economic Impact. Parasitology Today 14, 35-38.
- Pozio, E., 2000, Factors affecting the flow among domestic, synanthropic and sylvatic cycles of *Trichinella*. Veterinary Parasitology 93, 241-262.
- Pozio, E., 2001a, New Patterns of *Trichinella* infection. Veterinary Parasitology 98, 133-148.

- Pozio, E., 2001b, New patterns of *Trichinella* infection. *Veterinary Parasitology* 98, 133-148.
- Pozio, E., 2005, The broad spectrum of *Trichinella* hosts: From cold- to warm-blooded animals. *Veterinary Parasitology* 132, 3-11.
- Pozio, E., La Rosa, G., Murrell, K.D., Lichtenfels, J.R., 1992a, Taxonomic revision of the genus *Trichinella*. *Journal of Parasitology* 78, 654-659.
- Pozio, E., La Rosa, G., Rossi, P., Murrell, K.D., 1992b, Biological characterization of *Trichinella* isolates from various host species and geographical regions. *Journal of Parasitology* 78, 647-653.
- Pozio, E., La Rosa, G., Serrano, F.L., Barrat, J., Rossi, L., 1996, Environmental and human influence on the ecology of *Trichinella spiralis* and *Trichinella britovi* in Western Europe. *Parasitology* 113, 527-533.
- Pozio, E., Zarlenga, D.S., 2005, Recent advances on the taxonomy, systematics and epidemiology of *Trichinella*. *International Journal for Parasitology* 35, 1191-1204.
- Roberts, T., Murrell, K.D., Marks, S., 1994, Economic losses caused by foodborne parasitic diseases. *Parasitology Today* 10.
- Schad, G.A., Duffy, C.H., Leiby, D.A., Murrell, K.D., Zirkle, E.W., 1987, *Trichinella spiralis* in an agricultural ecosystem: transmission under natural and experimentally modified on-farm conditions. *Journal of Parasitology* 73, 95-102.
- Shoop, W.L., Cole, R.A., Corkum, K.C., 1987, The use of frozen carcasses in parasite surveys. *Journal of Parasitology* 73, 109.
- Singapore Customs 2004. *World Trade Atlas - Singapore*.
- Smith, H.J., 1975, An evaluation of low temperature sterilization of trichinae infected pork. *Canadian J. of comp. Med.* 39, 316-320.
- Smith, H.J., 1985, Infectivity of Canadian Isolates of *Trichinella spiralis navita* for Swine, Rats, and Carnivores. *Canadian J. of comp. Med.* 49, 88-90.
- Smith, H.J., 1987, Evaluation of ELISA for the serological diagnosis of trichinosis in Canadian swine. *Canadian Journal of Veterinary Research* 51, 194-197.

- Stark, K.D.C., Pfeiffer, D.U., Morris, R.S., 1998, Risk factors for respiratory diseases in New Zealand pig herds. *New Zealand Veterinary Journal* 46, 3-10.
- Stojcevic, D., Zivicnjak, T., Marinculic, A., Marucci, G., Anđelko, G., Brstilo, M., Pavo, L., Pozio, E., 2004, The epidemiological investigation of *Trichinella* infection in brown rats (*Rattus norvegicus*) and domestic pigs in Croatia suggests that rats are not a reservoir at the farm level. *Journal of Parasitology* 90, 666-670.
- Streiner, D.L.N., G.R., 1998, PDQ Epidemiology, 2 Edition. B C Decker Inc., London.
- Takahashi, Y., Mingyuan, L., Waikagul, J., 2000, Epidemiology of trichinellosis in Asia and the Pacific Rim. *Veterinary Parasitology* 93, 227-239.
- Tannock, G.W., McInnes, H., Shirley, G., Smith, J.M.B., 1971, Salmonellosis in sheep wintered outdoors on straw and sawdust pads. *New Zealand Veterinary Journal* 19, 29-32.
- Taylor, R.H., Thomas, B.W., 1993, Rats eradicated from rugged Breaksea island (170 HA), Fiordland, New Zealand. *Biological Conservation* 65, 191-198.
- Thomas, B.W., Taylor, R.H., 2001. A history of ground-based rodent eradication techniques developed in New Zealand, 1959-1993. In: *International Conference on Eradication of Island Invasives*, University of Auckland, pp. 301-310.
- Thornton, R., King, C., 2004, *Trichinella spiralis* disease investigation. *Surveillance* 31, 5-8.
- Thorsen, M., Shorten, R., Lucking, R., Lucking, V., 2000, Norway rats (*Rattus norvegicus*) on Fregate Island, Seychelles: the invasion; subsequent eradication attempts and implications for the island's fauna. *Biological Conservation* 96, 133-138.
- Thrusfield, M., 1995, *Veterinary Epidemiology*, 2nd Edition. Blackwell Science Ltd., Cambridge.
- Traweger, D., Slota-Bachmayr, L., 2005, Introducing GIS-modelling into the management of a brown rat (*Rattus norvegicus* Berk.) (Mamm. Rodentia Muridae) population in an urban habitat. *Journal of Pest Science* 78, 17-24.
- Twigg, G., 1975, *The Brown Rat*. David & Charles Inc., Vermont.

- United States Department of Agriculture, 2003, National Trichinae Certification Program: Draft environmental assessment, January 2003. USDA document, 1-32.
- USDA, 2003, National Trichinae Certification Program: Draft Environmental assessment, January 2003. USDA document, 1-32.
- van Knapen, F., 2000, Control of trichinellosis by inspection and farm management practices. *Veterinary Parasitology* 93, 385-392.
- Vignau, M.L., Guardis, M.V., Risso, M.A., Eiras, D.F., 1997, Comparison between two methods for diagnosis of trichinellosis: Trichinoscopy and artificial digestion. *Memorias do instituto Oswaldo Cruz* 92, 585-587.
- Vose, D., 2000, Risk Analysis - A Quantitative Guide, 2 Edition. John Wiley & Sons Ltd., Chichester.
- Wacker, K., Rodriguez, E., Garate, T., Geue, L., Tackmann, K., Selhorst, T., Staubach, C., Conraths, F.J., 1999, Epidemiological analysis of *Trichinella spiralis* infections of foxes in Brandenburg, Germany. *Epidemiology and infection* 123, 139-147.
- Wakelin, D., Goyal, P.K., 1996, *Trichinella* Isolates: Parasite variability and host responses. *International Journal for Parasitology* 26, 471-481.
- Ward, R.J., 1981. Diet and Nutrition. In: *Symposia of the Zoological Society of London*, London, U.K., pp. 255-266.
- Webster, P., Kapel, C.M.O., 2005, Studies on vertical transmission of *Trichinella* spp. in experimentally infected ferrets (*Mustela putorius furo*), foxes (*Vulpes vulpes*), pigs, guinea pigs and mice. *Veterinary Parasitology* In Press.
- Whiting, R.C.B., R.L., 1997, Development of a quantitative risk assessment model for *Salmonella enteridis* in pasteurized liquid eggs. *International Journal of Food Microbiology* 36, 111-125.
- World Health Organisation 1999. Principles and guidelines for the conduct of microbiological risk assessment CAC/GL-30 (World Health Organization).
- World organisation for animal health 2004. OIE - Annual animal health data (OIE).
- Wulf, D.M. 2005.